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DEVELOPMENT OF A PROCUREMENT SPECIFICATION FOR AN IN-LINE CONTA--ETC(U)

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U. S. NAVAL AIR ENGINEERING CENTER

LAKEHURST, NEW JERSEY

GROUND SUPPORT EQUIPMENT DEPARTMENT
NAEC-GSED-105 14 JUNE 1977

FINAL REPORT

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FOR AN
IN-LINE CONTAMINATION MONITORING UNIT

AIRTASK NO. A3400000/051B/5F41461400
WORK UNIT NO. 17

DEPARTMENT OF THE NAVY ★ NAVAL AIR ENGINEERING CENTER ★

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PREPARED BY J. J. COYLE

REVIEWED BY PETER B. SENHOLZI

APPROVED BY F. E. EVANS

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The Millipore Micro-Scan Contamination Monitor and the HIAC Analog Particle Counter (PC120) underwent laboratory and field test of their ability to measure particulate contamination. Two Aluminum Oxide Hygrometers were laboratory tested for their ability to measure water in MIL-H-5606 hydraulic fluid. The results of the testing formed the basis for a procurement specification for an in-line contamination monitor.

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1. INTRODUCTION

The objective of this study is to define the requirements for an in-line contamination monitoring device for aircraft hydraulic systems to be used with existing ground support equipment. In support of this objective various tasks were performed which included laboratory and field test of particulate measuring equipments, construction of a field simulator to be used with an AHT-64 hydraulic test cart to provide flow demand requirements, and the use of the simulator as part of a test loop for the in-line contamination monitor. Two aluminum oxide hygrometers were also tested to determine their ability to measure water contamination in MIL-H-5606 hydraulic fluid. With the information derived from this testing the requirements of the in-line contamination monitor were incorporated into a specification which could be used for procurement of suitable equipment.

2. SUMMARY OF PROCEDURES AND RESULTS

2.1 PARTICULATE CONTAMINATION MONITORS

2.1.1 PROCEDURES. Laboratory testing of the Millipore Micro-Scan and HIAC PC 120 was done to check their sensitivity to particulate contamination, to establish a method of calibration which could be adapted for field use, and to determine the effects of such parameters as flow rate, temperature and other flow conditions on the accuracy of the instrument readings. These findings were incorporated into the procurement specification. Laboratory test was to simulate field conditions to the maximum extent possible, and was followed by field test using an AHT 64 ground test cart and a simulator which represented an aircraft hydraulic system. Finally the units were tested at NAF, Warminster, Pennsylvania with aircraft.

2.1.2 RESULTS. Although measuring different contaminant characteristics, both the Millipore Micro-Scan and the HIAC PC 120 can be used as in-line contamination monitors. Both require controlled flow rate through the sensors, are susceptible to error due to entrained air or water, and are also susceptible to electronic interference. The Millipore Micro-Scan does not sense small particles, and the HIAC PC 120 does not sense large particles. They can be field calibrated, but more refinement of technique is necessary.

2.2. WATER CONTAMINATION MONITORS

2.2.1 PROCEDURES. Both the Millipore Micro-Scan and the HIAC PC 120 have an ability to detect free water, but there is need to quantitatively determine the amount of water present in aircraft hydraulic fluid. A potential means of doing this is the aluminum oxide hygrometer. Two different units were laboratory tested. These were the Panametric Model 2000 and the VeeKay Model VK 36. Test samples of MIL-H-5606 hydraulic fluid were prepared with known amounts of water and were checked using the Karl Fischer method of water determination, ASTM procedure D1744-64. The known amount of water was compared with the instrument readings and was checked for repeatability, effect of fluid temperature and speed of response. Neither in-line testing nor field testing was done.

2.2.2. RESULTS. Both hygrometers gave nearly a linear response to dissolved water, but calibration could not be maintained since the calibration curve shifted inexplicably from day to day. Both instruments were affected by fluid temperature, and both had a relatively slow response to abrupt changes in fluid condition.

3. CONCLUSIONS.

3.1 IN-LINE PARTICULATE CONTAMINATION MONITORS

a. Micro-Scan 2 does measure particulate contamination in MIL-H-5606 hydraulic fluid, but has the following deficiencies:

1) Insensitive to particles less than 10 micrometers in size.
2) Instrument calibration changes with time.
3) Sensor is sensitive to pump pulsations and must be isolated.

b. HIAC PC 120 does measure particulate contamination in MIL-H-5606 hydraulic fluid, but has the following deficiencies:

1) Insensitive to large particles.
2) Instrument calibration changes with time.
3) Low flow rate through sensor.

c. Both Micro-Scan 2 and HIAC PC 120 appear to be affected by electronic emission, and are sensitive to mechanical vibration.

d. There is need to learn more about particle generation in hydraulic systems and to learn more about the effects of contamination on system wear.

3.2 ALUMINUM OXIDE HYGROMETERS

a. Because of its interaction with chlorinated solvents, water in aircraft hydraulic systems is becoming an increasing problem. This is true for the P3 aircraft now, and may extend to other aircraft. If it does, there will be need for a ready means of detecting, measuring and removing excess water from aircraft hydraulic fluid.

b. Current aluminum oxide hygrometers are not suitable for measuring water content of MIL-H-5606 hydraulic fluid for the following reasons:

1) The meaning of the meter reading changes with time.
2) Speed of the response of the sensor makes it unsuitable for in-line monitoring.
3) Henry's Law constant of the hydraulic fluid changes for different fluid sources.

3.3. CALIBRATION OF IN-LINE CONTAMINATION MONITORS.

a. The method of calibration which requires a circulating loop and the addition of a known weight of contaminant to the fluid in the loop gave satisfactory results with both the Millipore Micro-Scan and the HIAC PC 120. It is more appropriate for laboratory calibration than it is for field calibration, however.

3.4. FIELD SIMULATOR

a. Test of the contamination monitor with actual aircraft is adequate, but the design could be improved. A study of the effects of turbulent versus non-turbulent flow would be helpful for establishing design parameters for the sampling section.

3.5. PROCUREMENT SPECIFICATION.

a. Specification tests and reliability and maintainability design parameters are based on best judgement and have been selected from requirements of reasonably similar equipments. A particulate contamination monitor is a unique equipment, not falling into any existing category.

4. RECOMMENDATIONS.

4.1. IN-LINE PARTICULATE CONTAMINATION MONITORS

a. Continue the development of contamination monitoring equipment to remedy deficiencies in existing equipment.

b. Study particle generation in aircraft hydraulic systems, its sources and the effects on component wear.

4.2. ALUMINUM OXIDE HYGROMETERS

a. Maintain close liaison with NARF Alameda and NAVAIR to keep updated on extent of problem with chlorinated solvents and need for support equipment to detect and measure water content in hydraulic fluid and to recondition the fluid.

b. Encourage the correction of deficiencies in present methods of measuring water in hydraulic fluid.

4.3. CALIBRATION OF IN-LINE CONTAMINATION MONITORS

a. Develop a method of field calibration of whichever contamination monitor is selected for procurement.

4.4. FIELD SIMULATOR

a. Study the effect of turbulent versus non-turbulent flow on the performance of in-line contamination monitors.

b. Improve the design of the sampling section of the contamination monitor.

4.5. PROCUREMENT SPECIFICATION

a. Verify validity of tests specified in procurement specification, and in reliability and maintainability design parameters.

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8. REPORT TEXT

8.1 Introduction The objective of this study is to define the requirements for an in-line contamination monitoring device for aircraft hydraulic systems to be used with existing ground support equipment (GSE). In support of this objective various tasks were performed.

8.1.1 Supporting tasks Supporting tasks include the following:

(1) Laboratory test of various contamination monitoring devices, such as:

(a) Microscan 1
(b) Microscan 2
(c) HIAC, PC 120
(d) Panametrics Hygrometer, Model 2000
(e) VeeKay Hygrometer, Model VK 36

(2) Construct a field simulator, using GFE aircraft parts, for simulating flow demand requirements for an aircraft hydraulic test cart, AHT-64.

(3) Using the field simulator conduct field test of selected contamination monitoring devices to assist in the definition of system requirements of these units.

(4) Prepare a procurement specification for an in-line contamination monitoring unit to be used with present GSE to measure the cleanliness of aircraft hydraulic systems.

8.2 Background

8.2.1 Previous work Reference (a) reports the results of field test of an in-line contamination monitoring device installed on an AHT 64, Aircraft Hydraulic Test Cart. Field test was conducted at NAS, Patuxent River, Maryland and at NAS, Cecil Field, Florida. Testing at Patuxent River was with several types of aircraft. Testing as NAS, Cecil Field, was limited to A7E aircraft. Patuxent River testing was conducted first to insure that no unforeseen operational problems existed with the modified AHT 64. This testing was conducted by Service Test Division personnel under controlled conditions, and test results were verified by both Service Test Division and by laboratory test of field samples of hydraulic fluid at Villanova University. Testing at NAS, Cecil Field was under normal operating conditions of Squadron VA 37 and served a dual purpose. It tested the behavior of the contamination monitoring unit under field conditions, and checked how the condition of hydraulic fluid in an aircraft system varied over a six month period. Field test results were again verified by laboratory test of field samples at Villanova University. The contamination monitoring unit used in these tests was a Micro-Scan Continuous Contamination Monitor manufactured by Millipore Corporation, Bedford, Massachusetts. This unit will subsequently be referred to as Micro-Scan 1.

8.2.2 Results of previous work Micro-Scan 1 measures particulate contamination by measuring the change in capacitance of a fluid as it flows through a restricted orifice. The change of capacitance is due to both the volume and nature of the contaminant present in the fluid. The results of previous test of this unit at Villanova University were reported in reference (b). The testing reported in reference (a) showed that in-line contamination monitoring was practical, and imposed no unexpected operating problems for aircraft maintenance personnel. Micro-Scan 1 was capable of performing its function without excessive maintenance, and did measure particulate contamination. In the measurement of particulates there were some anomalies in the data which could not be satisfactorily explained. Certain conjectures were possible, however. Laboratory testing had to be done on fluid samples taken from the hydraulic system, and the danger of contamination of such samples inadvertently is well known. Further, since Micro-Scan was sampling on-line, there was always the possibility that the distribution of contaminant throughout the system was not homogeneous so that the fluid sample for laboratory test, and what Micro-Scan 1 was seeing were not necessarily the same. The next step in the cycle was to develop a procurement specification for an in-line contamination monitor, taking into consideration what had been learned in these previous studies and allowing for new developments in the field of particulate measurement, and exploring what further capability could be introduced into the contamination measurement system.

8.3 Present Work

8.3.1 Early planning The current contract was received early in January, 1975. The early stages of work consisted of planning the testing and putting the test facility in order. John Kahrnak at the U.S. Army Mobility Command, Fort Belvoir, Va. was contacted for background material on what the Army had done about in-line contamination monitors, and John Zweers of HIAC was contacted to learn more about their latest development in contamination monitors, the PC 120. These contacts were most helpful in determining the future course of our effort.

After talking to Kahrnak and Zweers, it became evident that HIAC had an instrument which could be used as an in-line contamination monitor as well as Microscan, although a different parameter was being measured. It was readily available, could be set alongside the Microscan, and they could be used to check each other. Accordingly, a HIAC PC 120 was procured with a 4-120 micron sensor.

The jenny which had been modified for use at NAS Cecil was put back into its original configuration since it had been decided to keep the contamination monitor a separate unit which might be used with any jenny. The considerations of the laboratory test loop for

additional testing were also considered, and it was decided to use the loop which had been used for previous laboratory tests, but to arrange to tap that loop from one of the quick disconnect fittings which were available on it. Flow to the contamination monitors would be assured by throttling the main loop flow downstream of the tap to the monitor loop flow. Preliminary testing of Microscan showed it to be sensitive to flow rate, and it was decided to install a flowmeter in the monitor loop to insure steady flow conditions. An existing flowmeter was modified for this purpose by constructing a new float which permitted a maximum flow in excess of 1.0 gpm.

8.3.2. Preliminary testing The HIAC PC 120 was received on March 5, 1975 and it was decided to install both it and the Microscan in series in the monitor loop. Since the two units had different flow requirements, a by-pass of the HIAC sensor had to be provided, and since special piping arrangements had to be made, provisions were also provided for backflushing the HIAC sensor, and for calibrating the sensor using premeasured test samples of fluid which could be procured from HIAC. Initial testing of Microscan and HIAC PC 120 showed a lack of sensitivity in the Microscan unit to AC fine test dust. This was the same experience noted in previous laboratory testing. Other contaminants were considered for lab testing, but in view of ANSI acceptance of AC fine test dust for its specification on the calibration of particle counters, it was felt that the Navy should use the same standard. About this time Millipore advised that it was developing a more sensitive version of Microscan which would have better capability in detecting ACFTD. This was expected to be available in September, 1975, and so further test of the contamination monitors was shelved at this point, and more emphasis was put on water measurement and the development of an aircraft hydraulic system simulation device for use in field test with the jenny which was available.

8.3.3. Test of Aluminum Oxide Hygrometers In the testing at NAS Cecil, one of the causes of erratic data was believed to be water in the hydraulic fluid. The Microscan sensor is very sensitive to the presence of free water. Also, water is one of the contaminants present in hydraulic fluid which should be measured. The only reliable way now available to measure total water content of hydraulic fluid is the Karl Fischer Method, ASTM test method D1744-64. This is a laboratory type procedure and of no use for field testing. The aluminum oxide hygrometer is a possible candidate for field test of water. It is made by two companies; one is Panametrics, a division of Esterline-Angus, and the second is VeeKay, Ltd. Both use the same type of sensor, but their output displays vary.

The Panametrics hygrometer is also used by the Navy for measuring the water present in Nitrogen gas in aviator's breathing systems. One of these units was borrowed from NAEC, and its capability tested in the laboratory and compared with Karl Fischer measurements.

The NAEC Panametrics hygrometer was received on May 5, 1975 and subjected to test. It was returned to NAEC in July, 1975. Arrangements were also made to borrow a VeeKay hygrometer from the local representative, Mr. Scott Hazel, and test it under similar conditions to those of the Panametrics hygrometer. The VeeKay hygrometer was tested from July 29 to 31, and returned to Mr. Hazel on August 6.

8.3.4. Construction of hydraulic system simulator During the summer months of 1975 work continued on the design and construction of the aircraft hydraulic system simulator. It was built from spare hydraulic system parts provided by the NAEC. The simulator was completed and used for the first time on September 19. Considerable trouble had been experienced with operating the ground test cart. The blower drive belt was a continuing source of trouble, and several belts had to be procured. The belt had a tendency to slip off the pulley. When this occurred the belt stretched on one side and couldnot be used again. Eventually this difficulty was overcome.

8.3.5. Specification development A rough draft of the procurement specification for the contamination monitor was completed in late October, 1975. Several meetings with NAEC were held to discuss various aspects of the procurement specification. One was on December 15, 1975, another on August 7, 1975, and a third on February 22, 1976. The next specification revision was put out on April 30. 1976.

8.3.6. Test of In-line Contamination Monitors Although the new contamination monitor from Millipore, Microscan 3, was expected in September, 1975, it did not arrive until January, 1976. After its receipt, testing of the new unit with the HIAC was accelerated. This testing phase culminated with field test of both units at NAF Warminster on May 3 and 4.

8.4. Testing of In-line Contamination Monitors Testing of Micro-Scan 2 and the HIAC PC 120 for sensitivity to contamination began after receipt of Micro-Scan 2 on January 5, 1976. Prior to this time Micro-Scan 1 had been subjected to various tests to check variation of meter reading with flow rate and temperature. It was found that both contamination monitors have a meter output which varies with flow rate. Variation of meter output with temperatures in the range of 90^{o}-130^{o} did not occur. Because of the sensitivity of flow rate a flowmeter was installed in series with Micro-Scan. The HIAC was delivered with a flowmeter.

The test set-up for this testing is shown in Figure 1 and Photo 1. The Micro-Scan 2 and HIAC PC 120 were installed in series. Because of the disparity of flow rates of the two instruments, Micro-Scan 2 is 0.3 gallons per minute and the HIAC sensor is 30 milliliters per minute, a by-pass was provided for the HIAC sensor The special plumbing for the HIAC sensor allowed not only for bypass flow, but also back-flushing, and calibration flow as shown in Fig.2 and Photo 2.

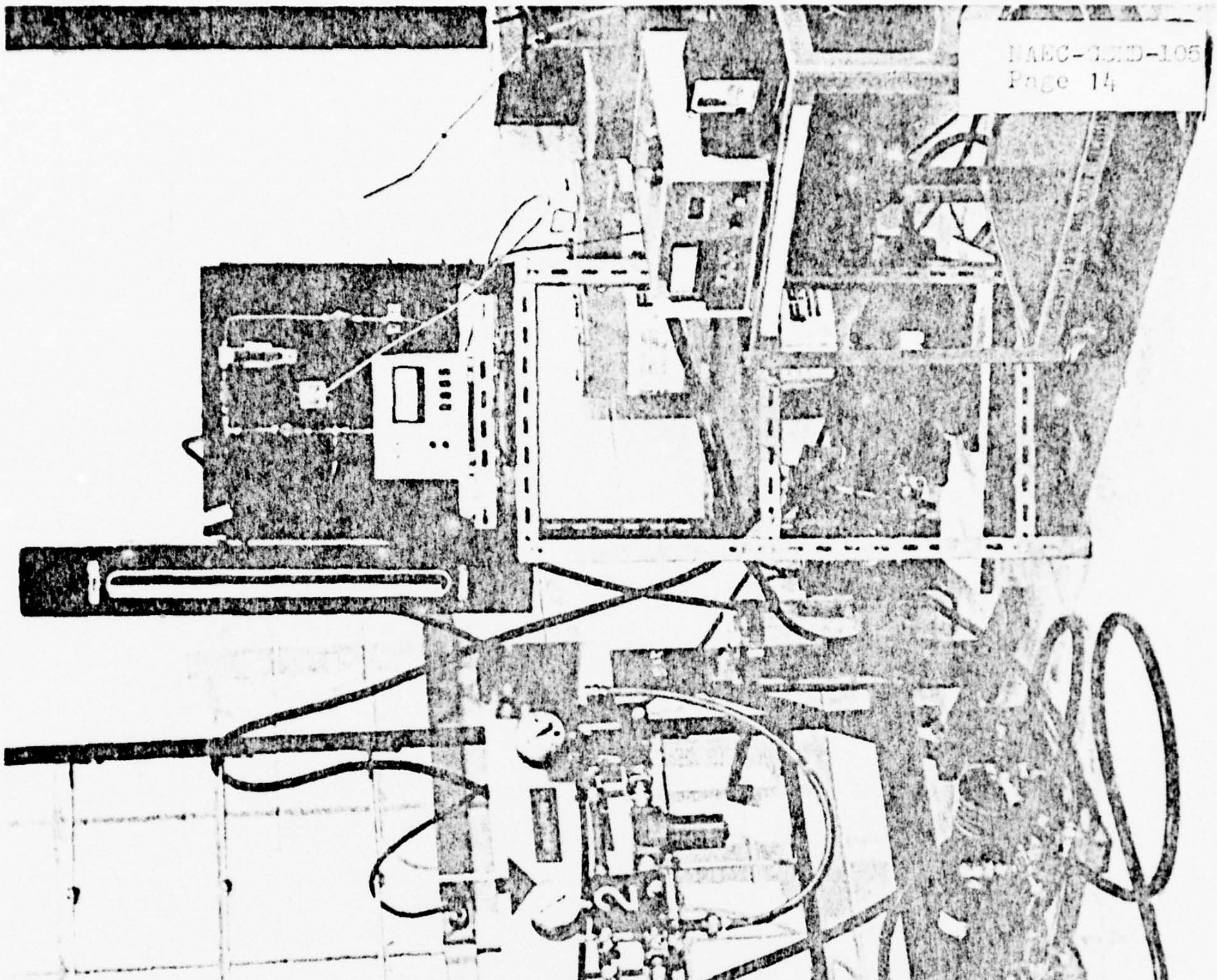


Photo #1
Laboratory Test Set-up

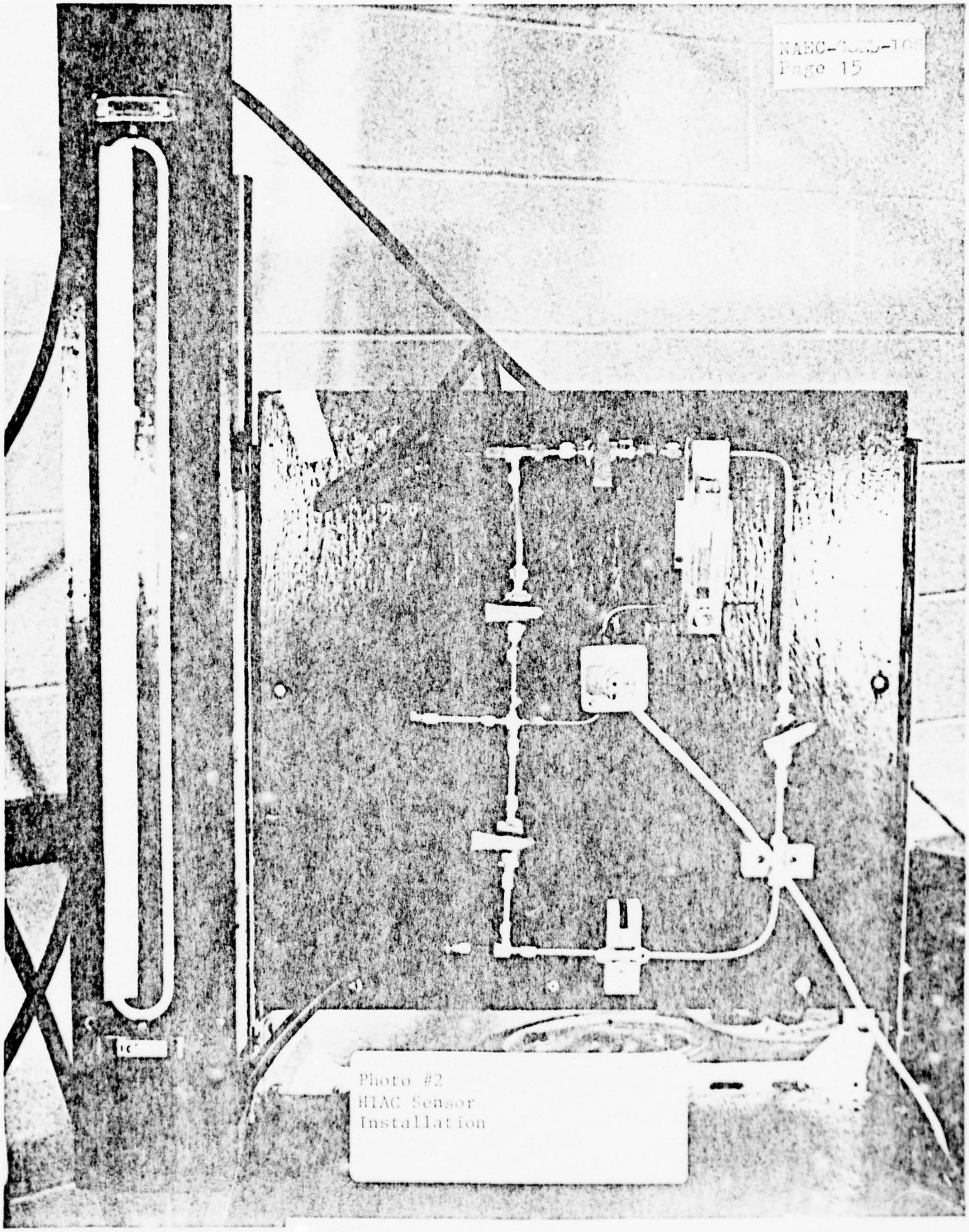


Photo #2
HIAC Sensor
Installation

Back-flushing provisions are necessary to clear the sensor orifice should flow be restricted by a large particle. The normal method of calibrating the HIAC sensor is by flowing hydraulic fluid with a known particle count through the HIAC sensor and recording particle count and potentiometer setting. The calibration procedure is discussed in more detail elsewhere in this report. The calibration chart for the HIAC is shown in Figure 3.

The test loop pump was an Eastern Industries Model 2J34E, a two stage centrifugal pump Style CZZCAT, serial number CB-0792. It was driven by an electric motor Type 40000Z MP, 115/230 volts, 12/6 amperes, 1 horsepower, 3450 RPM. A centrifugal pump was used because of the requirements of Micro-Scan. The centrifugal pump is free of pressure fluctuations which might affect contamination meter readings. In addition a small accumlator was installed upstream of Micro-Scan to smooth out the flow even more. Details of Micro-Scan 2 and HIAC PC 120 are given in the following paragraphs.

8.4.1 Micro-Scan Continuous Contamination Monitor Micro-Scan is made by Millipore Corporation, Bedford, Mass., 01730. Micro-Scan is designed for the determination of particulate contamination and free water in both hydraulic fluids and fuels. The basic principle of operation is the measurement of the capacitance change of a fluid flowing through a restricted orifice. Particulates and free water in the fluid cause this capacitance change. The amount of the capacitance change is proportional to the volume of the contaminant. This change is translated into a voltage pulse of fixed duration and height. The resultant pulse train is processed through a series of amplifiers to yield a measure of the contaminant level on a meter. The meter can be set to a predetermined threshold value; and, if this level is exceeded, a warning alarm is activated.

There are two variations of Micro-Scan. Micro-Scan 1 (Photo 3) was designed to be used for monitoring aviation fuel. It continuously samples the main stream flow at a rate of 1.3 gallons per minute and requires a 20 psi pressure drop. This unit was modified for use with hydraulic fluid to have a smaller gap between capacitor plates, and it is finer tuned electronically to increase its sensitiviity. Flow rate of the modified unit is 0.9 gallons per minute and requires a 25 psi pressure drop. Micro-Scan 2 (Photos 4 and 5) is a redesigned unit of lighter weight, small size, simplified construction and requires 0.3 gallons per minute flow with a pressure drop of 50 psi. Principal specifications are shown in Table 1.

Output of both models is a meter and paper tape recorder if desired. The meter scale is graduated from 0-100 and has two ranges 0-100 and 0-10. Both models have warning lights for "No Power", "No Flow" and contamination in excess of pre-set value. These warning systems can be used to control other electrical equipment.

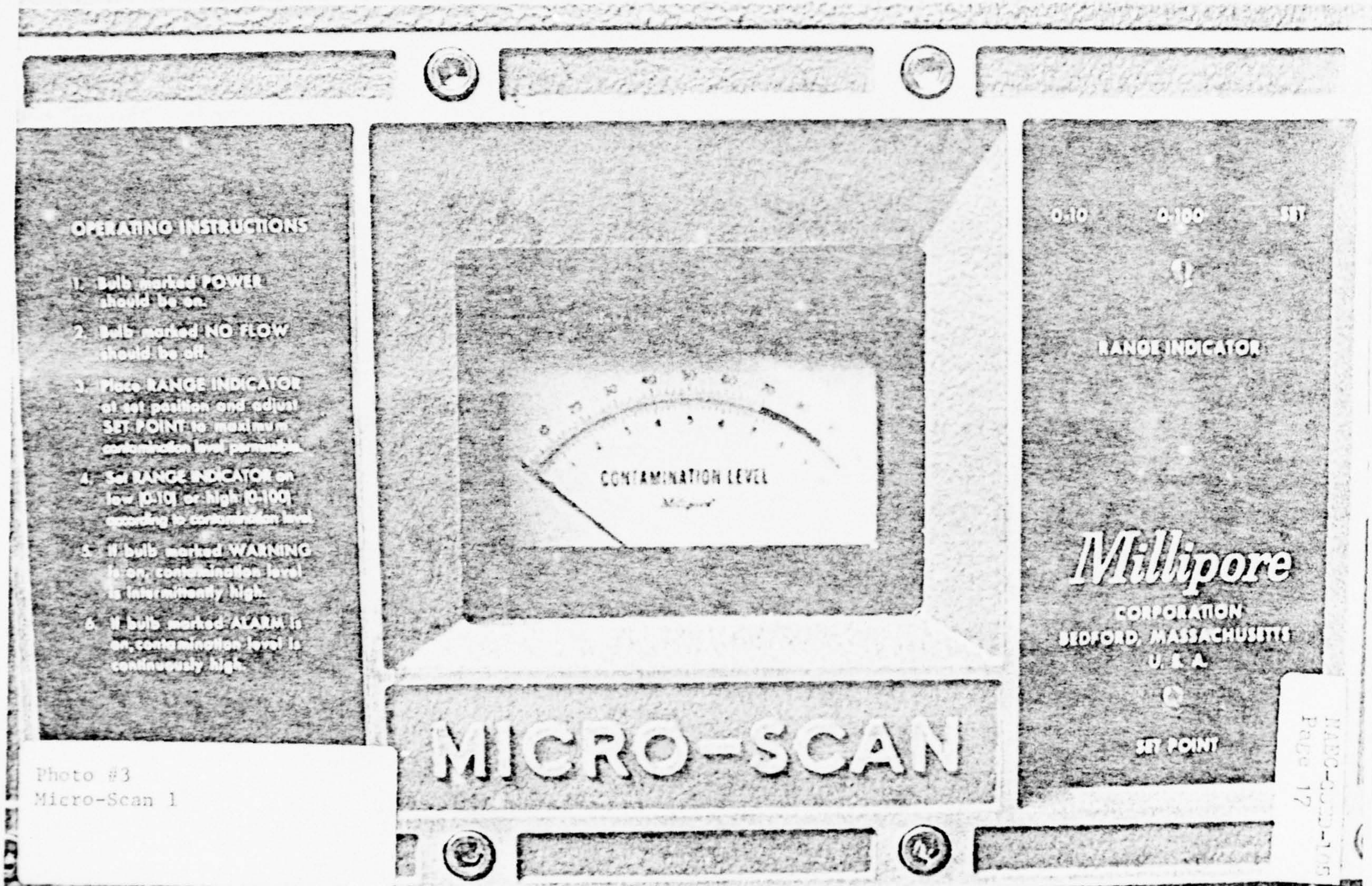


Photo #3
Micro-Scan 1

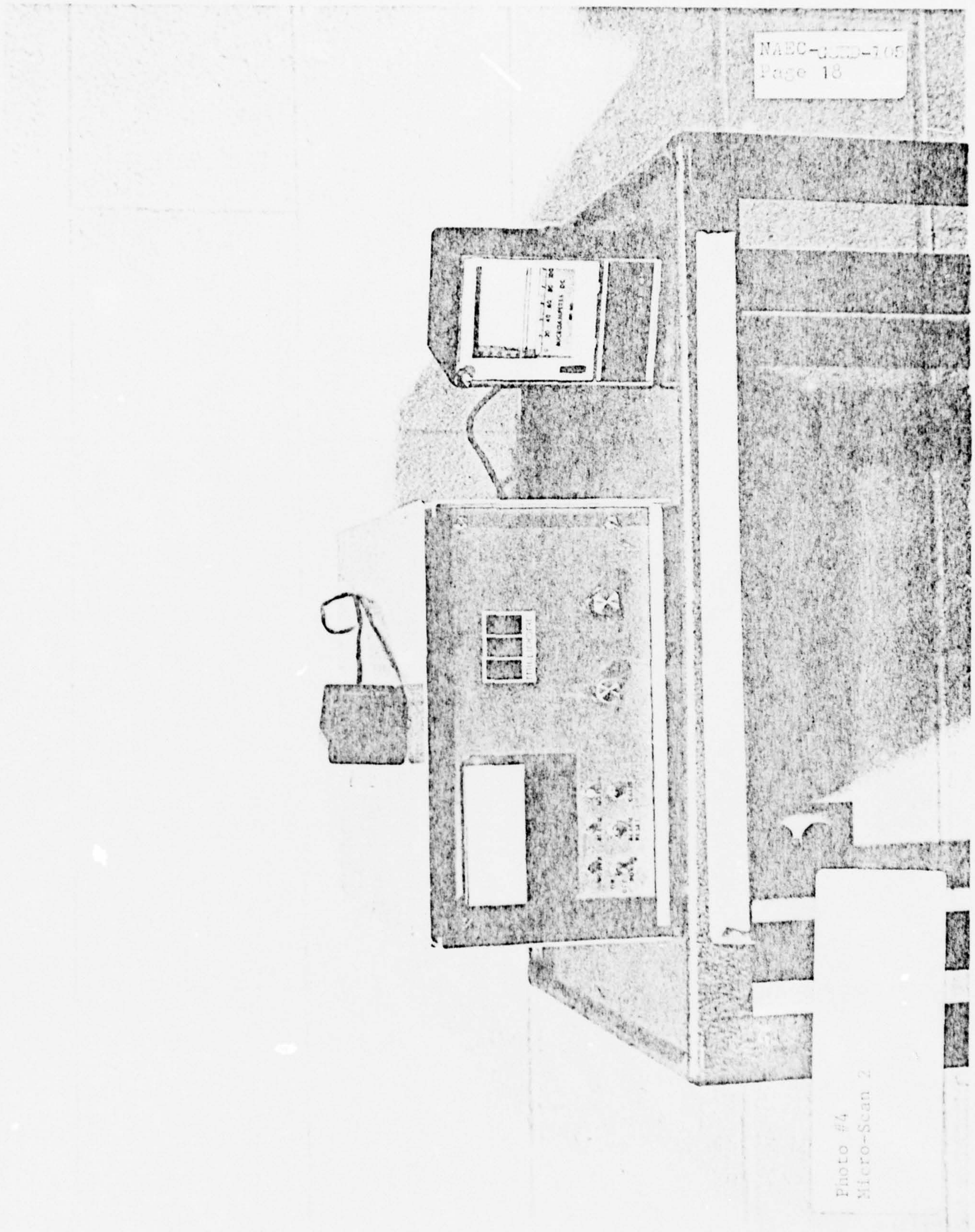


Photo #4
Micro-Scan 2

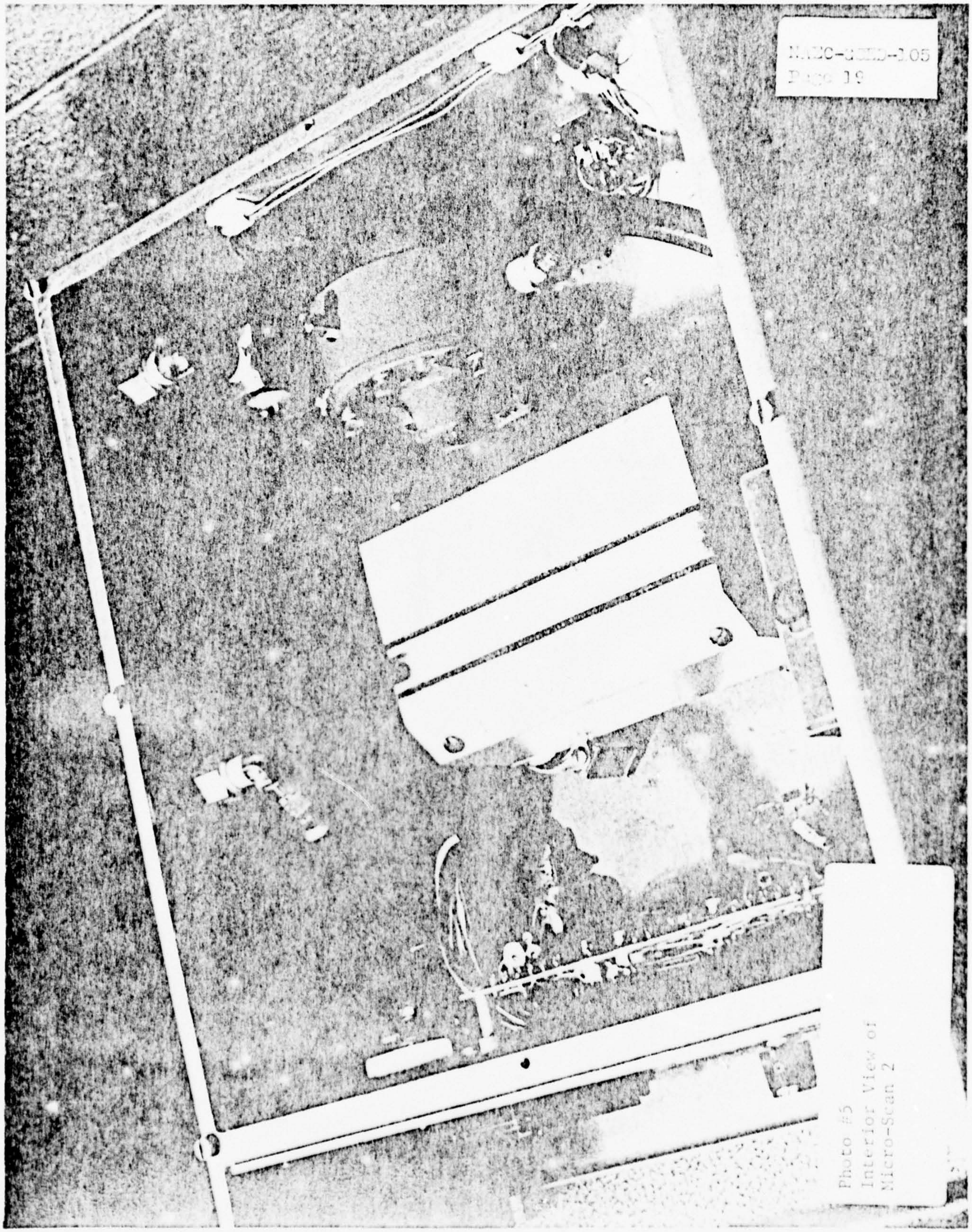


Photo #5
Interior View of
Micro-Scan 2

TABLE 1

MICRO-SCAN SPECIFICATIONS

	1		2
Overall dimensions	14 3/4 in. 17 5/8 in. 10 1/4 in.		7 in. 10 in. 14.in.
Weight	78 lbs.		12 lbs.
Sampling flow rate	1.3	0.9	0.3 gpm
Pressure drop	20	25	50 psi
Operating voltage	110 V 60 Hz	12 VDC	110 V 60 Hz or 12 VDC
Operating current	.25 Amp	-	-
Temperature range	-20^{o} to $+50^{o}$ (all models)		
Sensitivity - by weight	0.1 mg/gal solids (Note 1) 0.01 ppm (entrained water) (Note 1)		

Note 1 - These are specifications for Model 1 from handbook and are dependent upon electrical characteristics of contaminant.

8.4.2 Model PC-120 Contamination Monitor The Model PC-120 Contamination Monitor (Photo 6) is made by the HIAC Division, Pacific Scientific Company, PO Box 3007, 4719 West Brooks Street, Montclair, California 91763.

It is a single channel particle counter with an adjustable particle size threshold and a continuous analog output proportional to particles per second through the sensor. Outputs can be used for analog meter display, strip chart recorder, automated data acquisition system, and the alarm system (panel light or remote device.) The automatic alarm circuit signals when upper or lower pre-set concentration limits have been exceeded.

Input may be from the standard HIAC "CM" sensor powered by the PC-120 or by other HIAC counters. Sensors are rated to 3000 psi and 200°F. They may be located as far as 1000 feet from the PC-120. No adjustment is required for varying colors of liquids. Selection of particle size sensitivity is directly dialed on a potentiometer located behind the front face of the unit.

Output analog meter display has four size ranges: 0-100, 0-300, 0-1000, and 0-3000 particles per second. Flow rate through the sensor is dependent upon the sensor size. For this application the 4-120 micrometer sensor was used and the flow rate chosen was 30 milliliters per minute. There is a saturation limit to the unit which will be discussed later.

The principle of operation of the HIAC PC-120 with sensor is to electronically measure the amount of light blockage which occurs when a particle passes between a light source and a phototube. The fluid passage chamber is so small that particles flow through one by one. Light is collimated by the long, tunnel-shaped window into a parallel beam through the chamber window. Whenever a foreign particle passes by the window, a fraction of the light beam is interrupted. This causes a momentary reduction in the output signal from the phototube which is proportional to the size (projected area) of the particle passing through the light beam. This signal change is then sent to the counter sensitivity control which has been preset to a specific threshold limit.

The PC-120 without sensor weighs approximately 20 pounds and is 6" x 8" x 14" in size. Its power requirements are 100-240 VAC, 50-60 Hz.

8.4.3. Test Procedure and Results On January 6, 1976 Micro-Scan 2 and the HIAC PC 120 were connected in series as shown in Figure 1. Flow through each sensor was at the recommended rate: 0.3 gpm for Micro-Scan 2 and 30 ml/min for the PC 120. The PC 120 sensor by-pass valve was adjusted to regulate flow through its sensor. Flow to Micro-Scan 2 was regulated by throttling the main loop flow so that there was

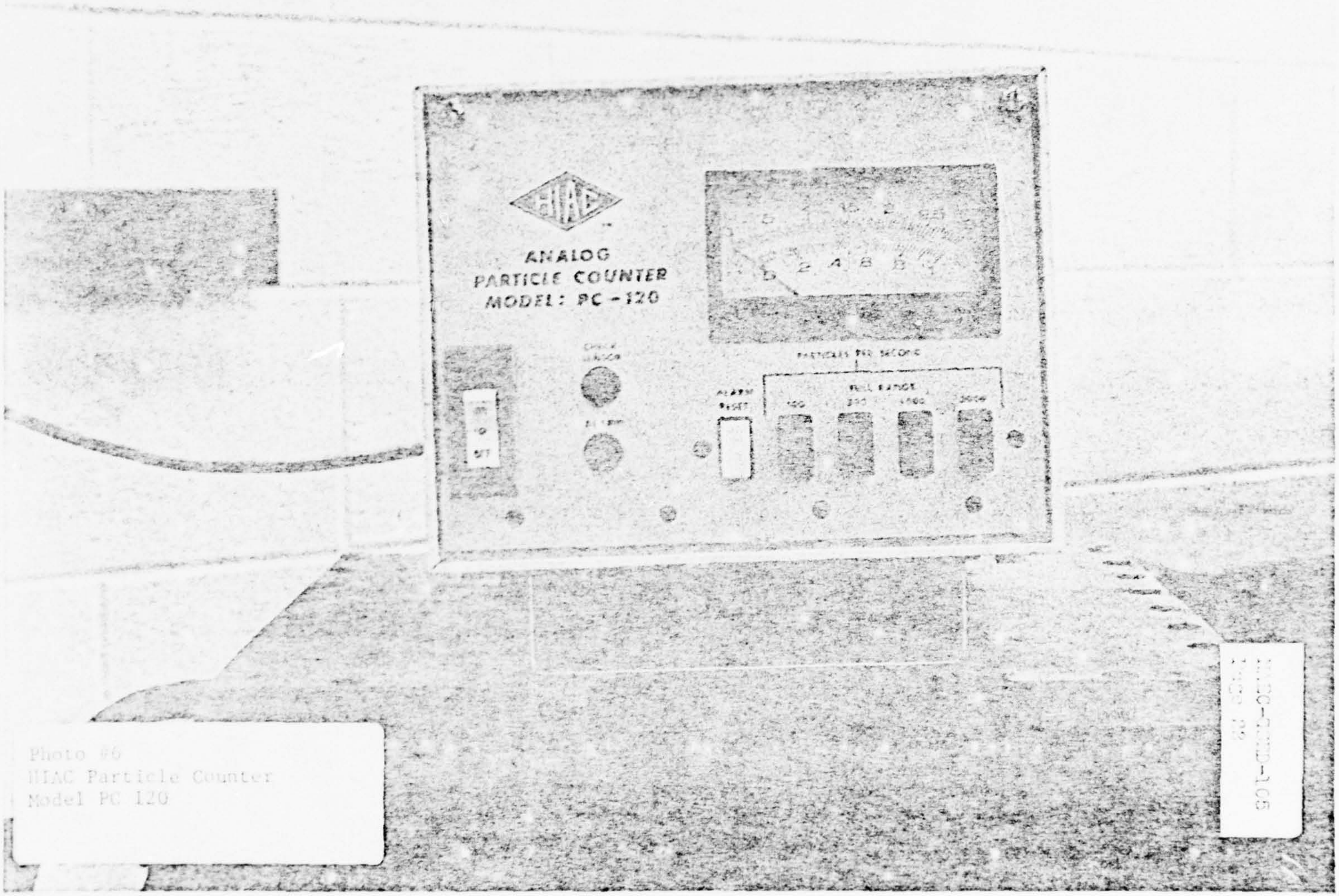


Photo #6
HIAC Particle Counter
Model PC 120

a pressure differential between the monitoring loop inlet and outlet. The main loop flow was filtered through existing Micro-Tube filters until a minimum reading was obtained on the Micro-Scan meter. This was used as a base level of cleanliness.

AC fine test dust (ACFTD) was added to the main loop reservoir and agitated with an electric stirrer. When Micro-Scan meter readings stabilized, meter reading of both Microscan and PC 120 were recorded. Gravimetric samples and samples for PIMC analysis were taken from a sample tap in the main test loop. The results of these measurements are shown in Table 2.

Gravimetric analysis, although it does not accurately reflect the dirt added, still shows that the fluid at the beginning of test was excessively dirty. This was further borne out by PIMC and PC 120 particle counts. It appears that the contamination level of the hydraulic fluid at the start of test was in excess of 10 milligrams per liter. Class 5 cleanliness is in the 1 to 3 mg/l range.

As dirt was added to the test loop the Micro-Scan meter advanced as shown in Figure 4. Agreement between HIAC and PIMC readings is as shown in Figure 5. The HIAC and PIMC particle counts confirm the gravimetric measurements. It should be noted that a lower limit of sensitivity of 13 micrometers was chosen to avoid reaching a saturation limit of the HIAC counter which occurs at a concentration value of about 2600 particles per milliliter.

Although there appears to be good agreement between HIAC and PIMC readings at the greater than 10 micrometer level, at 25 micrometers and above, HIAC readings are much lower than PIMC particle counts. The HIAC meter reads counts per second. At a flow of 30 ml/min it takes 2 seconds for 1 ml to pass the sensor. Readings in Table 2 have been corrected to counts/ml for comparison with PIMC counts.

Because of the high level of background contamination at the start of test it was decided to repeat the testing, taking care to eliminate the problems encountered. Changes in test procedure include the following:

a. Substitute a three stage centrifugal pump in the main test loop to insure turbulent flow conditions. The 3 stage pump is an Eastern Industries, Hamden, Conn. Model 3J-34E, Type 107-2, Style CZZIBATJT, Serial CI 3-003, driven by a 1 HP, 115 Volt AC motor at 3450 RPM.

b. Replace micronic filters in the main hydraulic loop to insure system cleanliness.

c. Install a pre-filter upstream of the Micro-tube filters to remove greater than 10 micrometer particles and reduce the amount of contaminant reaching the Micro-tube filters.

d. Use the present two stage centrifugal pump for circulating fluid through the Micro-Scan and HIAC sensors.

e. Provide a sample tap for PIMC and gravimetric samples just upstream of Micro-Scan 2.

A line diagram of the test loop incorporating the above changes is shown in Figure 6.

During the testing of January 5 and 6 it seemed that the HIAC count was influenced by the degree of by-pass around the HIAC sensor. To check this further tests were conducted. The HIAC sensitivity was set to measure particles greater than 10 micrometers, and the following counts recorded: particle count - 1025 cps, by-pass closed, HIAC flow - 30 ml/min, total flow - 30 ml/min; particle count - 950 cps, by-pass open, HIAC flow - 30 ml/min, total flow - 0.3 gpm. The difference does not appear to be significant.

Testing was repeated on February 9 and March 4 using the modified test loop. Test results are listed in Tables 3 and 4. Because of the tendency of both sensors to experience flow blockage from particles which would not pass through, it became evident that a better method of back-flushing was needed so a four way valve was obtained and installed as shown in Figure 7 and Photo 7. This test arrangement was used for test at NAF, Warminster, Pa. and for laboratory test on May 12. The testing at NAF, Warminster will be discussed later. Test results of the May 12 testing are shown in Table 5.

8.4.4. Discussion and Analysis The testing of 2/9, 3/4, and 5/12 was to check the accuracy and repeatability of measurement of Micro-Scan 2 and HIAC PC 120.

8.4.4.1. Comparison of HIAC and PIMC Particle Counts Agreement between HIAC and PIMC readings on 1/9 for particulates greater than 10 micrometers in size appeared reasonably good. A check on this particle size on 2/9 and 3/4 is shown in Figure 8. There is some deviation at contaminant concentrations exceeding 400 counts per milliliter, and the initial slopes of the curves appear to vary somewhat, but in the Class 5 cleanliness range the agreement is good. The data of 5/12, however, shows wide disagreement between HIAC and PIMC counts. This is shown in Figure 9. The HIAC count appears to be excessively high and the slope of the line through the data points is 0.5. For agreement between the two counts the slope should be 1.0. This agreement was further checked at greater than 6 and 15 micrometers respectively, and is shown in Figures 10 and 11. The greater than 6 micrometer counts are well into the saturation level for HIAC and are of little value for comparison. The greater than 15 micrometer data shows closer agreement, but the slope of the line approximating the data points has a slope of

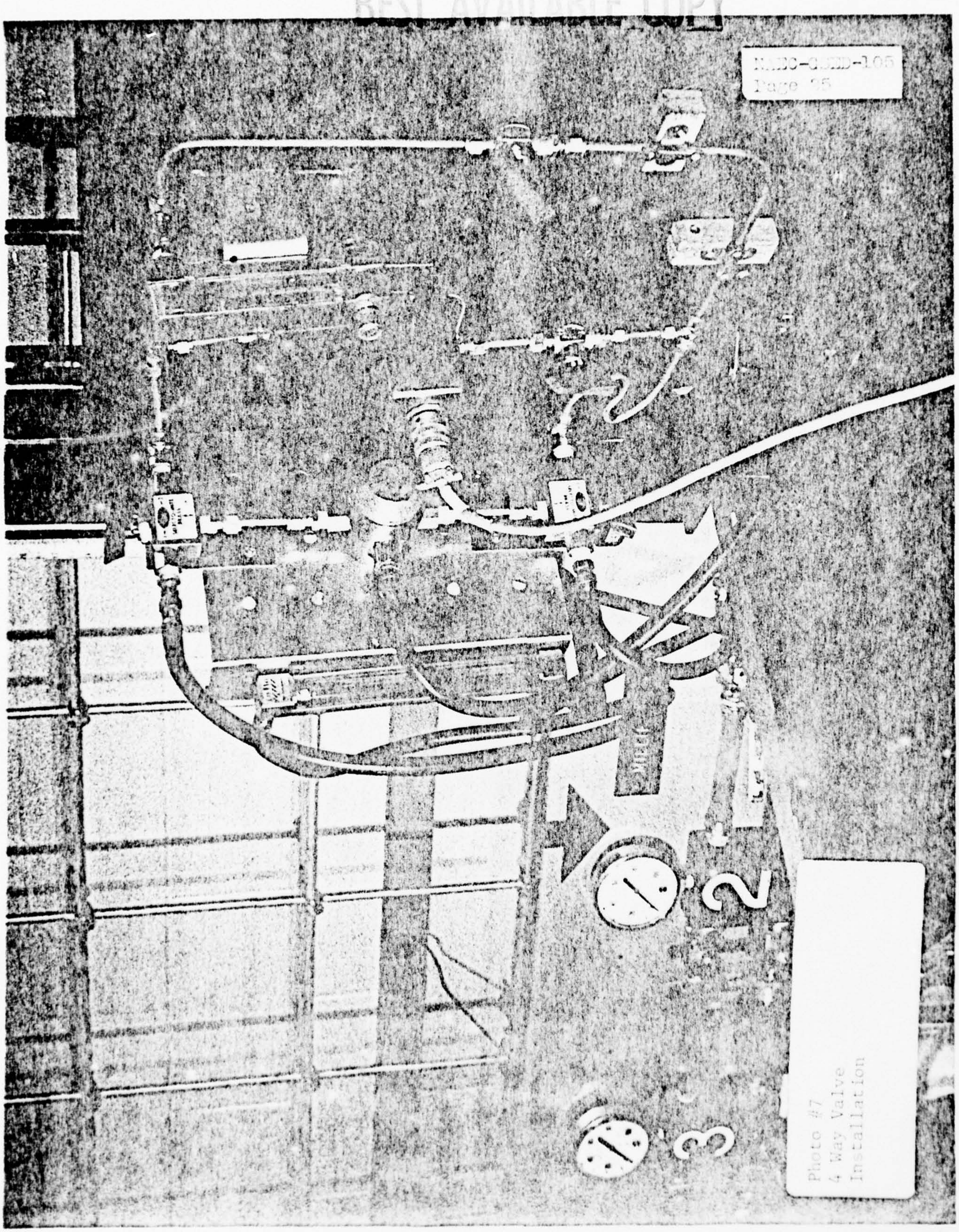


Photo #7
4 Way Valve
Installation

.225 which is very much less than the desired 1.0.

8.4.4.2. Comparison of HIAC and PIMC particle counts with Contamination Level in milligrams per liter. Figures 12, 13, and 14 show particle counts plotted against contamination level for particle sizes greater than 5, 10, and 15 micrometers. In Figure 12 only the PIMC count is shown because the PC 120 could not count that small a particle. For comparison a standard distribution count is also plotted to show what the slope should be. Data for the standard distribution is from Table 3 of reference C. The fact that the actual count started at greater than 2000 particles shows that the Micro-tube filter was unable to clean the test loop below this level. What is important is the slope of the curve. The slope should be 517 particles per mg/l. The actual slope was 1000. This indicates a greater ingestion of contaminant than planned if the counts are accurate and the contaminant used had the desired distribution. Figures 13 and 14 show counts for greater than 10 and 15 micrometers. HIAC counts, although high, show slopes which are close to the standard distributions. The PIMC counts, on the other hand, although closer to the expected count, show a definite change of slope in the vicinity of 2.5 to 3.0 mg/l. The reason for this change of slope is not known. The contaminant which was added to the test loop reservoir was pre-mixed in one concentrated solution, and added in measured quantities to achieve the desired level of contamination. Between times for measuring volumes for adding to the test loop, the concentrated contamination mixture was continually agitated. In the 5/12 test the only other difference in test procedure was that HIAC and Micro-Scan were in parallel instead of in series in the contamiantion monitoring loop. Figure 15 shows PIMC particle count against contamination level for particles greater than 5, 10, and 25 micrometers. The fact that initial contamination level was not absolutely clean will be reflected in a count level vertically displaced from the standard distribution level. This was not taken into account for the 10 and 25 size levels, but 1000 was added to the 5 micrometer count to bring the standard distribution up closer the the actual particle counts. The aberrations of the 5/12 particle counts are evident in this portrayal as well as that seen previously, but no additional light is shed on the reason why.

8.4.4.3. Comparison of Micro-Scan meter readings with PIMC count and Contamination Level in milligrams per liter. Figure 16 compares Micro-Scan meter reading with PIMC count for particles greater than 10 micrometers. The data of 2/9, 3/4, and 5/12 are plotted on the same chart with the Class 5 cleanliness level also shown. It appears that two different sensitivity curves result. On 2/9 Micro-Scan was much more sensitive than it was on the other two dates. It seems that the electronics of Micro-Scan are susceptible to detuning with time. This characteristic is also apparent in the plot of Micro-Scan meter reading against contamination level in mg/l which is shown in Figure 17. Previous testing of Micro-Scan, references a and b, are shown in Figure 18 with present test results superimposed. In reference b, the sensitivity of Micro-Scan 1 was shown for two different contaminants. The sensitivity to ACFTD was shown to be very much less than the sensitivity to iron oxide. Reference a described testing of Micro-Scan 1 at both

NAS, Patuxent River, Maryland and NAS, Cecil Field, Florida. The sensitivities at these two sites were different when exposed to actual service type contaminants. Now we have the results of this most recent testing of Micro-Scan 2 with ACFTD and have found two different levels of sensitivity which appear to match somewhat closely the Patuxent and Cecil results. It would appear that the performance of Micro-Scan as measured by its sensitivity to ACFTD has improved markedly, but the sensitivity is not constant.

8.4.4.4. Field Test of Micro-Scan 2 and HIAC PC 120 at NAF, Warminster, Pa. on May 3 and 4, 1976. The first use of the four way valve for back-flushing was during field test at NAS, Warminster. The two stage centrifugal pump was used to provide flow to the contamination monitors, and they were paralleled for this testing. The testing procedure had first been tried using the AHT 64 and field simulator at Villanova, and no problems were encountered using the simulator.

On May 3 an AHT 63 was connected to the utility system of CH-53A, BuNo 161590. The contamination monitors connected to the return line from the aircraft to the ground test cart. The CH-53 has three separate hydraulic systems. Operating system pressure is 3000 psi. The only components connected to the utility system which could be operated were the loading ramp doors. Flow in the return line was less than 2 gpm. With a fluid temperature of 126°F and a sampling pump pressure of 45 psig the following readings were obtained:

Micro-Scan 2	Flow - 1300 ml/min (.34 gpm)
Meter reading 26	
HIAC PC-120	Flow - 30 ml/min
Counts/second -	100 greater than 6 micrometers 4 greater than 10 micrometers

The Micro-Scan and HIAC readings were not in accord. The former indicated a much higher level of contamination than the latter. The return line flow rate of 2 gpm was too low for meaningful results, and so it was decided to test another aircraft.

On the afternoon of May 3 test of US-2B, BuNo 133054, began. The US-2 has only one hydraulic system which operates at 1500 psi. This was an aircraft which was undergoing routine maintenance, and the contamination level was expected to be higher than that of the first aircraft. Before testing could start several incidents occurred:

a. The hydraulic test cart reservoir overflowed

b. Air got into both the aircraft and contamination monitor systems. The source of the air was not known, but everything had to be bled to remove it.

Testing for the day was suspended.

On May 4 testing resumed on the US-2, and more incidents occurred:

a. A section of the aircraft hydraulic system had been removed for maintenance during the evening work shift, and the hydraulic lines had not been capped. When pressure was applied to the aircraft system a considerable quantity of hydraulic fluid had been lost, and had to be replaced.

b. The HIAC sensor gave evidence of blockage. Back-flushing did not clear the condition. The sensor was removed and blown out with compressed air with no improvement. The lamp adjustment did clear the condition and the warning light went out.

c. Just before lunch both the Micro-Scan and HIAC gave spurious signals for no apparent cause. One possible explanation is that high frequency emissions were affecting both electronic circuits. This might also have been the cause of the high Micro-Scan reading of the previous day.

After lunch, reasonably stable readings were obtained on both instruments. By operating the bomb-bay doors, tail hook and flight controls a flow of 3 to 7 gpm was obtained in the test cart return line. Pump pressure in the monitoring loop limited the Micro-Scan flow to 500-550 ml/min (0.13gpm). HIAC flow was 30 ml/min. Meter readings and corresponding PIMC counts for typical readings are given in Table 6.

It appears that the aircraft hydraulic systems cleanliness was somewhere around Class 5 cleanliness level. For Sample 1 Micro-Scan gave an abnormally high reading. For Sample 2 the HIAC meter reading was unsteady. Several times during test the Micro-Scan meter exceeded the full scale reading of 100 for no apparent cause. It might have been either air or electronic interference. It took about 1 1/2 minutes for the results of an actuator movement to reach the monitor. The bomb-bay door actuators appeared cleaner than either the tail-hook or rudder actuators. This could be detected on the contamination monitors. When hydraulic flow from the aircraft ceased, Micro-Scan readings would decrease to a meter reading of 2 while the monitor loop flow recirculated. Several times during test the sensitivity of the HIAC was set to measure particles greater than 10 micrometers in size. A particle count of about 10 particles/ml was a typical reading.

The testing at NAF, Warminster showed that both contamination monitors can be used to measure cleanliness in aircraft systems, but there were several problems:

a. Aircraft return line flow should be in the turbulent range for representative sampling.

b. Both contamination monitors give erratic readings under certain conditions, possible due to air or electronic interference.

c. Micro-Scan 2 must have a pump of sufficient capacity to provide design flow requirements regardless of return line pressure.

d. Operating personnel should be more familiar with the ground hydraulic test cart.

e. The hydraulic hoses and pump of the contamination monitoring unit should be designed so that they are readily transportable and store easily so that they are not a hazard to maintenance personnel.

8.4.5. CONCLUSIONS.

a. Micro-Scan 2 does measure particulate contamination in MIL-H-5606 hydraulic fluid, but has the following deficiencies:

(1) Insensitive to particles less than 10 micrometers in size.

(2) Instrument calibration changes with time.
(3) Sensor is sensitive to pump pulsations and must be isolated.

b. The HIAC PC 120 does measure particulate contamination in MIL-H-5606 hydraulic fluid, but has the following deficiencies:

(1) Insensitive to large particles.
(a) Instrument calibration changes with time.
(3) Low flow rate through sensor.

c. Both Micro-Scan and HIAC PC 120 appear to be affected by electronic emission, and are sensitive to mechanical vibration.

d. There is need to learn more about particle generation in hydraulic systems and to learn more about the effects of contamination on system wear.

8.4.6. RECOMMENDATIONS.

a. Continue the development of contamination monitoring equipment to remedy deficiencies in existing equipment.

b. Study particle generation in aircraft hydraulic systems, its sources and the effects on component wear.

8.5. TEST OF ALUMINUM OXIDE HYGROMETERS

8.5.1. Hygrometers - General The quantity of water in petroleum products is customarily measured by the Karl Fischer method (ASTM procedure D 1744-64). This is a laboratory method of determining the total water content. It is highly desirable to find a simpler method which might be used at the flight-line level of maintenance to determine water content in MIL-H-5606B aircraft hydraulic fluid. One possible approach to this is the use of a hygrometer similar to Panametrics Model 2000 or VeeKay Model VK-36 for measuring water content. Both of these make use of a sensor which consists of an aluminum strip which has been anodized by a special process to provide a porous oxide layer. A very thin coating of gold is evaporated over this structure. The aluminum base and the gold layer form the two electrodes of an aluminum oxide capacitor which provides a measure which can be related to vapor pressure and dissolved water content in an organic liquid. This is not the same water content measured by the Karl Fischer reagent method. The Karl Fischer method measures total water content which includes both dissolved and free water content of the fluid. The hygrometer measures only the former. This lesser capability is acceptable for field use. Visual inspection will usually, reveal saturated fluid. The hygrometer has the potential of measuring water content in excess of specification limits, but still unsaturated.

To determine the weight content of water within an organic fluid Henry's Law must be applied. Henry's Law states that the mass of gas dissolved by a given volume of solvent, at constant temperature, is proportional to the pressure of gas with which it is in equilibrium. The parts per million by weight of water in organic liquids is equal to the partial pressure of water vapor times a constant. Thus, Henry's Law constant must be computed separately for each fluid. It is the saturation percent of water for the solvent in question divided by the saturation vapor pressure of water at the temperature of measurement. Once this constant is known, the weight percent of water in the organic fluid is computed by multiplying this constant times the vapor pressure of water measured by the probe.

8.5.2. DESCRIPTION OF EQUIPMENT, TEST PROCEDURE, AND RESULTS.

8.5.2.1. Panametrics Model 2000 Tests were made on MIL-H-5606B hydraulic fluid using a Panametrics Model 2000 hygrometer and M2 probe, serial number 2114-H. Specifications for this hygrometer are given in Table 7. A picture of the equipment is shown in Photo 8. The results of the test are shown in Figure 19.

8.5.2.1.1. Test Procedure The Panametrics hygrometer was borrowed from the Ground Support Equipment Division of the Naval Air Engineering Center, and a calibration curve for the probe was not provided. To correlate scale reading with the water content of the fluid, samples of hydraulic fluid were prepared with various water contents. A Karl Fischer type analysis was performed on each sample to determine

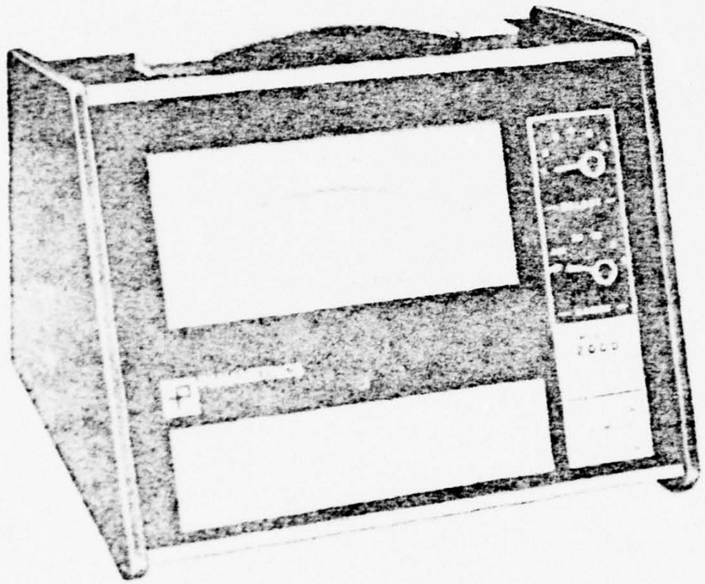
Photo #8
Panametrics Hygrometer
Model 2000

Moisture Minder Model 2000

from

PANAMETRICS, INC.

221 Crescent St., Waltham, Mass. 02154
Tel. 617 899-2719
Telex 92-3406



- Measures dew point in both liquids and gases.
- One probe covers a range from +20°C to −110°C.
- Independent of flow rate.
- Low cost per unit measurement.
- Connects to any standard multi-point recorder.

the actual water content. Hygrometer readings were taken on the same samples, and the resulting relationship found is plotted in Figure 19. There were 23 data points covering a range of water contents from 38 to 442 ppm. The Karl Fischer tests were reproducible to within 2 ppm for the same sample. The relationship was linear, and correlation was excellent. This testing was done about the middle of June.

8.5.2.1.2. <u>Determination of Dew Point</u> The calibration curve relates meter reading to dew point. Since no calibration curve was provided, it was decided to prepare a calibration curve using a fluid for which the Henry's Law constant is known. Normal hexane was chosen for this purpose. Twelve hexane samples of known water content, measured by the Karl Fischer method, were also measured by the hygrometer. Knowing Henry's Law constant and water content, the dew point was calculated. The relationship is graphically portrayed on the nomogram shown in Figure 20.

At this point the hygrometer was returned briefly to NAEC. When it came back again to Villanova, the meter readings for the previously prepared samples were significantly different. Readings for July 9 are also shown on Figure 19. A meter reading of 3.0 meant a water content of 250 ppm in mid-June, but only 93 ppm in early July. No cause for this aberration was apparent. It vitiated the dew point calculations of the preceding paragraph. Shortly after July 9, the Panametrics hygrometer had to be returned to NAEC for other use which precluded further testing. However, a VK-36 hygrometer made by VeeKay, Ltd., became available for test. The VK-36 makes use of the same principles for determining dissolved water as the Panametrics Model 2000.

8.5.2.2. <u>VeeKay Hygrometer, Model VK-36</u> Specifications for the VK-36 hygrometer are listed in Table 8. This hygrometer had Probe No. 74085. A calibration curve for this probe is shown in Figure 21. A picture of the hygrometer is shown in Photo 9. Both hygrometers had been used for water measurements on July 9 before a meter failure on the VeeKay hygrometer prevented further measurements. A comparison of readings of the two instruments are shown in Figure 22. The Panametrics hygrometer has a pointer and scale for measuring, while the VK-36 has a digital readout. The scale readings only have meaning when calibrated against dew point or the partial pressure of water. On July 28 testing was resumed on the VK-36 hygrometer after repair of the digital output meter. The results are shown in Figure 23. The same shift of calibration noted for the Panametrics hygrometer was also noted for the VK-36.

VEEKAY

HYGROMETER

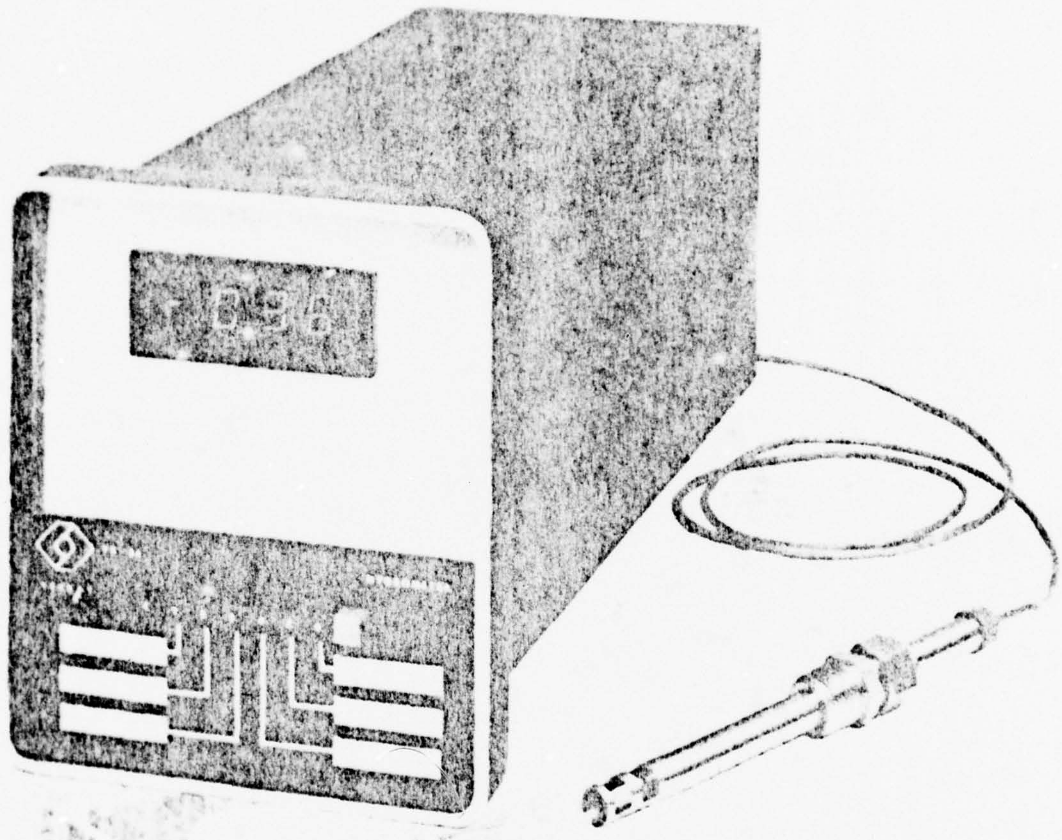


Photo #9
VeeKay Hygrometer
Model VK 36

MODEL 36

8.5.2.3. Effect of Temperature on Hygrometer Reading. Further test of the VK-36 hygrometer was conducted. First, the effect of temperature on the hygrometer readings was measured. The hygrometer probe was inserted in a three necked flask partially filled with MIL-H-5606B hydraulic fluid with a water content of 204 ppm. A thermometer was inserted through the second neck of the flask, and the third neck was stoppered so that the fluid was not exposed to the atmosphere during test. Tests were conducted on July 31 and August 5 with the results shown in Figure 24. Once again the calibration changed between tests.

8.5.2.4. Variation of Henry's Law with Temperature Using the results of testing on August 5 a Henry's Law constant was calculated using the nomogram, Figure 20. The results appear to be quite close to the results obtained by taking saturation values from previous tests conducted at Villanova and reported in Reference d. The constant was obtained from the VK-36 measurements by taking the known quantity of water in the fluid, 204 ppm, obtaining the dew point from the probe calibration curve and reading the constant using the left side of the nomogram. The constant was obtained from reference d. data from the saturation concentrations at known temperatures and using the right side of the nomogram. The variation of Henry's Law constant with temperature is shown in Figure 25.

8.5.2.5. Time Response of VK-36 Hygrometer. Another test made on the VK-36 hygrometer was a measurement of the time it takes to get a final reading. This is shown in Figure 26.

8.5.3. Discussion and Analysis The measurement of water content of MIL-H-5606 hydraulic fluid did not appear to be a problem in a previous study made by Villanova University, reference e. However, recent experience with the P3 aircraft, overhauled at NARF Alameda, has revealed that water in combination with Freon, a solvent used in aircraft maintenance, appears to be the cause of excessive corrosion in the hydraulic system of this aircraft. The extent to which this combination is affecting other aircraft is under investigation by the Navy. Water is also detrimental in that it can affect the additives which are present in hydraulic fluid, can cause degradation of the fluid, and can be the breeding ground for undesirable organisms. For these reasons the water content of hydraulic fluid should be controlled; but first, it must be measured.

The laboratory method of measuring water content is not readily adaptable for field use. The aluminum oxide hygrometer appears to have this potential although there exist some inherent problems. One of these is the dependence of the aluminum oxide hygrometer on Henry's Law which relates to the saturation concentration of water in hydraulic fluid. A previous study, reference d, showed that the saturation concentration of water in hydraulic fluid varied not only with temperature, but also with the source of manufacture of the fluid. In spite of this, the simplicity of operation of the aluminum oxide hygrometer makes it attractive for field use. This hygrometer only has to be immersed in the fluid being tested to obtain a meter reading

which can be related to water content. Unfortunately, laboratory test of the Panametrics and VeeKay hygrometers showed other failings, common to both.

The major deficiencies of the aluminum oxide hygrometer revealed by this testing are two. First, the inability of both instruments to give consistent meter readings from day to day which is seen in Figures 19, 23, and 24 is a major drawback which must be corrected before any practical use of them can be made. Second, the response time of both instruments to a change in water content is excessive. For the VeeKay instrument this is shown in Figure 26, but it was experienced with both hygrometers. The Panametrics specification states that the instrument has a response time of less than 5 seconds for a 63 percent step change in moisture content in either wet up or dry down cycle. This specification was not met.

The variation of hygrometer reading with temperature is a lesser problem if the variation of the Henry's Law constant with temperature can be determined. The variation of the water saturation limit of hydraulic fluid which also affects the Henry's Law constant is also a problem, but could be relieved by tighter fluid specifications.

8.5.4. CONCLUSIONS AND RECOMMENDATIONS.

8.5.4.1. Conclusions

a. Because of its interaction with chlorinated solvents, water in aircraft hydraulic systems is becoming an increasing problem. This is true for the P3 aircraft now, and may extend to other aircraft. If it does, there will be need for a ready means of detecting, measuring and removing excess water from aircraft hydraulic fluid.

b. Aluminum oxide hygrometers are not suitable for measuring water content of MIL-H-5606 hydraulic fluid for the follwing reasons:

(1) The meaning of the meter reading changes with time.
(2) Speed of response of the sensor makes it unsuitable for in-line monitoring.

(3) Henry's Law constant of the hydraulic fluid changes for different fluid sources.

8.5.4.2. RECOMMENDATIONS

a. Maintain close liaison with NARF Alameda and NAVAIR to keep updated on extent of problem with chlorinated solvents and need for support equipment to detect and measure water content in hydraulic fluid and to recondition the fluid.

b. Encourage the correction of deficiencies in present aluminum oxide hygrometers, and continue to look for other methods of measuring water in hydraulic fluid.

8.6. CALIBRATION.

8.6.1. General Calibration is necessary to insure that equipment is measuring consistently each time it is used, and when compared with other similar equipments. A satisfactory method of calibration is necessary for an effective quality control program. Until the last few years in the science of particulate measurement there was little accord between individual researchers for lack of an agreed upon standard. Recently, however, progress has been made by the American National Standards Institute in publishing a standard method for the calibration of liquid automatic particle counters using "AC" fine test dust, reference c. This was further extended to microscopic type automatic particle counters, and in a "round robin" type test involving both type of particle counters, use of the calibration procedures resulted in agreement in count of common samples within 20 percent, reference f. For the in-line contamination monitor being considered in this study an additional problem is presented.

Our present problem is two-fold. First, the desired output of the in-line contamination monitor is a simple indication of "clean" or "dirty", and is not a particle count. Second, the instrument which might be used for measuring cleanliness is not necessarily a particle counter. It might be an instrument similar to the Millipore Micro-Scan which is not a particle counter. The Navy standard for acceptable cleanliness is based on allowable number of particulates in the range of 5 micrometers and greater, but the present test method for field use requires no count, only a color comparison with a given standard.

The two equipments tested for suitability as in-line contamination monitors are good examples of the two different methods of measuring fluid cleanliness. The HIAC PC 120 is a particle counter, and the Millipore Micro-Scan is not. Any procedures developed for calibrating these instruments should be adaptable both for field calibration and for measuring conformance to specification requirements for procurement.

8.6.2. Calibration Procedures Several calibration procedures were tried. First, the HIAC particle counter was calibrated using the manufacturer's recommended procedure. HIAC provides fluid with a known particle count which can be passed through the sensor and meter readings recorded for given sensitivity settings. This method is not applicable to the Millipore Micro-Scan. For the latter, a gravimetric method of measurement is more appropriate. Two gravimetric methods were tried. One method uses matched weight filters and measures the weight change for a given volume of fluid passing through. In the second method, the meter reading is noted for different contamination levels of the fluid and the results plotted to show the sensitivity of the instrument to known changes of contamination level. Since cleanliness is defined by particle count, fluid samples at each contamination level are also subjected to counting to insure that cleanliness standards are satisfied. This last method is applicable to either type of contamination monitor and forms the basis for the requirement

which was eventually incorporated into the procurement specification, Appendix A.

8.6.2.1. HIAC PC 120. The contractor's recommended procedure for calibrating particle counters had to be modified to meet the unique requirement of the PC 120 which is an analogue type particle counter. The conventional particle counter counts the total number of particles of a given size in a specific volume of fluid. The analogue type counter measures the rate of counting, in this case, particles per second. For the analogue counter the flow rate must be controlled. This was accomplished by putting the test fluid with the known particle count into a pressure chamber, pressurizing the chamber using a minimum of 40 psig to force the fluid through the PC 120 sensor, and recording the meter reading for different potentiometer settings. Photo 10 shows the pressure chamber and Figure 27 shows a cross-section of the test set-up. A magnetic stirrer is used to agitate the fluid during calibration. For this reason the base of the pressure chamber should be non-magnetic in nature so that it does not interfere with the stirring action. With a known flow rate through the sensor, the meter reading of counts per second can be converted into particle count per milliliter. Since the test fluid has a known particle count per milliliter for particular size particles, the potentiometer setting for a given size particle can be determined. A typical calibration curve is shown in Figure 28.

8.6.2.2. Millipore Micro-Scan. The Millipore Micro-Scan lends itself more to gravimetric methods of calibration. The usual technique for gravimetric analysis is the matched weight filter. Two cellulose filters of a given pore size are contained in a plastic holder. A volume of fluid is passed through the two filters and the increase in weight of the top filter is measured and recorded. This gives the weight of contaminant present in a specified volume of fluid, usually milligrams per liter. The results of these measurements were not precise as can be seen from the data in Tables 2, 3, and 4. For the volumes used, the quantity of dirt was very small, and subsequent check showed that the matched weight filters as received from the manufacturer and weight differences which were in excess of the weight of contaminant.

Gravimetric measurement of contaminant cannot be related directly to particle count except a specific contaminant which has a known particulate distribution. "AC" fine test dust is such a contaminant which makes it a useful standard for testing. This is one of the reasons that it is used by the American National Standards Institute for its calibration procedures. Table 3 of reference C lists the particle size distribution for 1 mg/l of "AC" fine test dust.

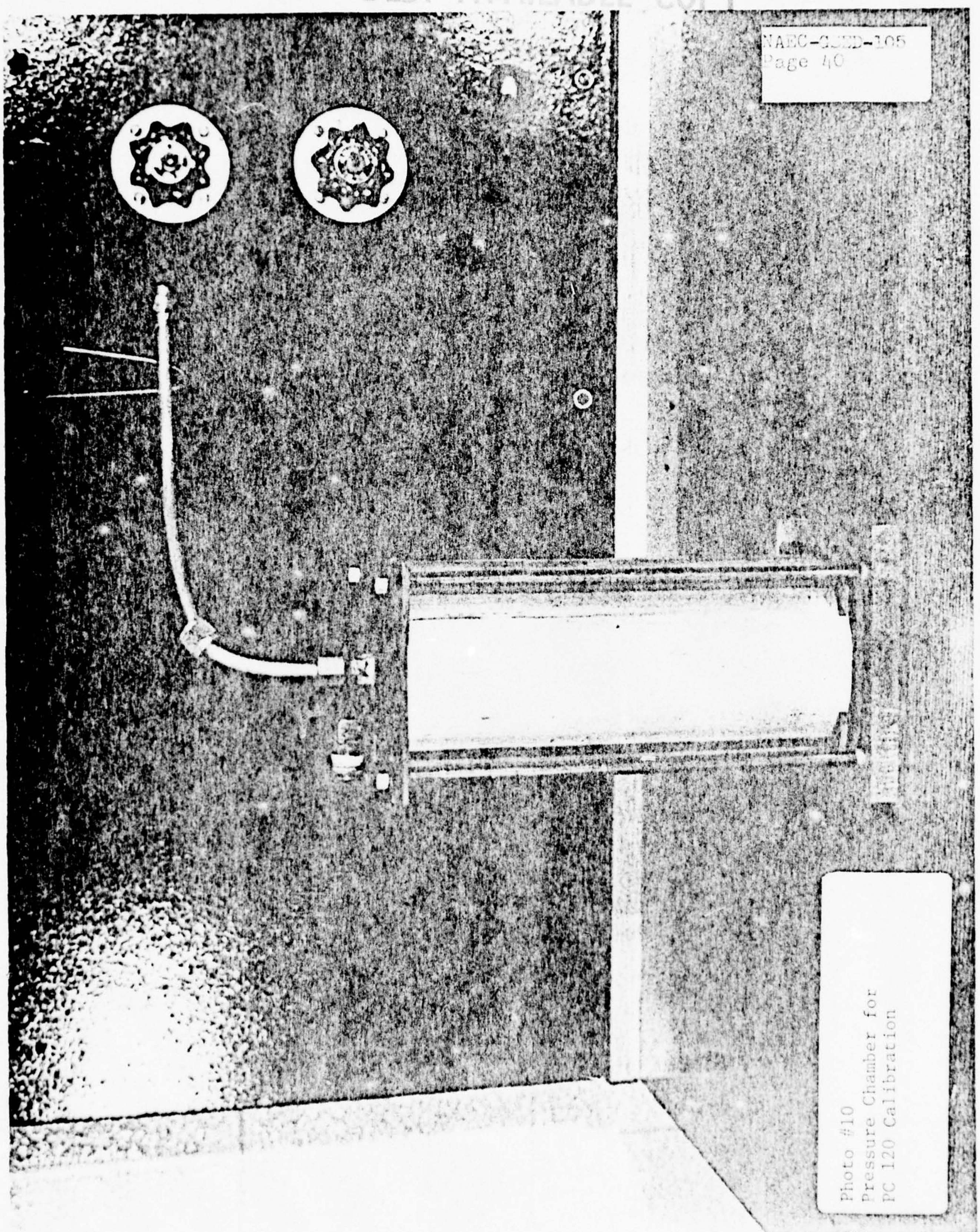


Photo #10
Pressure Chamber for
PC 120 Calibration

The next method considered for the calibration of the Millipore Micro-Scan was to add a known weight of contaminant to the circulating fluid in a test loop, and then pass a portion of this flow through the Micro-Scan and record its meter readings for each contamination level. A sample of fluid was drawn just upstream of Micro-Scan for a particle count to verify the contamination level that the sensor was experiencing. This last method gave satisfictory results, and was also used for the HIAC PC 120, and was used as the basis for contamination measurement in the procurement specification, Appendix A.

8.6.3. Conclusion The method of calibration which requires a test loop and the addition of known weight of contaminant to the circulating fluid in the test loop gave satisfactory results with both the Millipore Micro-Scan and the HIAC PC 120. It is more appropriate for laboratory calibration than it is for field calibration of the instruments, however.

8.6.4. Recommendation It is recommended that further study be given to a method of field calibration of whichever contamination monitor is selected for procurement.

8.7. CONSTRUCTION AND USE OF FIELD SIMULATOR. It was intended to test the in-line contamination monitors under conditions which approached service conditions as closely as possible. The purpose of such testing was to discover any problems which simple laboratory test might overlook. To accomplish this field testing, it was planned to use the AHT 64 hydraulic test cart which had previously been modified for use at NAS, Patuxent River and NAS, Cecil Field, and to connect the cart to a field simulator which would represent the aircraft hydraulic system.

8.7.1. MODIFICATION OF AHT 64 TEST CART. The AHT 64 test cart, as used previously, had been modified to have Micro-Scan 1 connected internally to the test cart return line. A pump was installed to provide flow to Micro-Scan 1. Power for Micro-Scan 1, the pump, and a recorder was derived from the test cart batteries. Micro-Scan 1 had been modified for this purpose. Since the concept of use had changed since the previous testing, all of the installed equipment was removed from the AHT 64 test cart. It was now the intent to keep the contamination monitor a separate unit, apart from the test cart and connect into the test cart return line externally. As now envisaged, the in-line contamination monitor was to consist of three units:

a. Sampling unit. This included the adapter for the test cart return line, connectors and hoses for supply and return lines to the contamination monitor, and a pump to provide the required flow volume.

b. Sensor unit. This unit is installed in hydraulic lines and provides a signal to the analytical unit which is proportional to the amount of contamination detected.

c. Analytical unit. This unit receives the signal from the sensor and has the circuitry to transform that signal to a form which can be displayed on an output meter.

8.7.2. CONSTRUCTION OF A FIELD SIMULATOR. To simulate the aircraft hydraulic system a field simulator was constructed of excess aircraft hydraulic parts. Photo 11 is a picture of the aircraft hydraulic system simulator. Figure 29 is a schematic drawing of the unit. It consists of two linear actuators controlled by an electrically operated four way valve. Power for the valve was provided by the batteries of the AHT 64 test cart, and a timing switch was installed in the power line to the valve so that the linear actuators could be electrically cycled. A second hydraulic circuit included a rotary hydraulic motor with an on-off valve, manually operated installed in the line. The rotary hydraulic motor was coupled to a small DC generator to provide loading for the motor. The AHT 64 provided hydraulic fluid flow to the simulator, and return flow from the simulator was to the hydraulic test cart. The adapter of the sampling unit of the in-line contamination monitor was located between the return hose from the field simulator and the AHT 64 return coupling. Photo 12 is a picture of the return line sampling section.

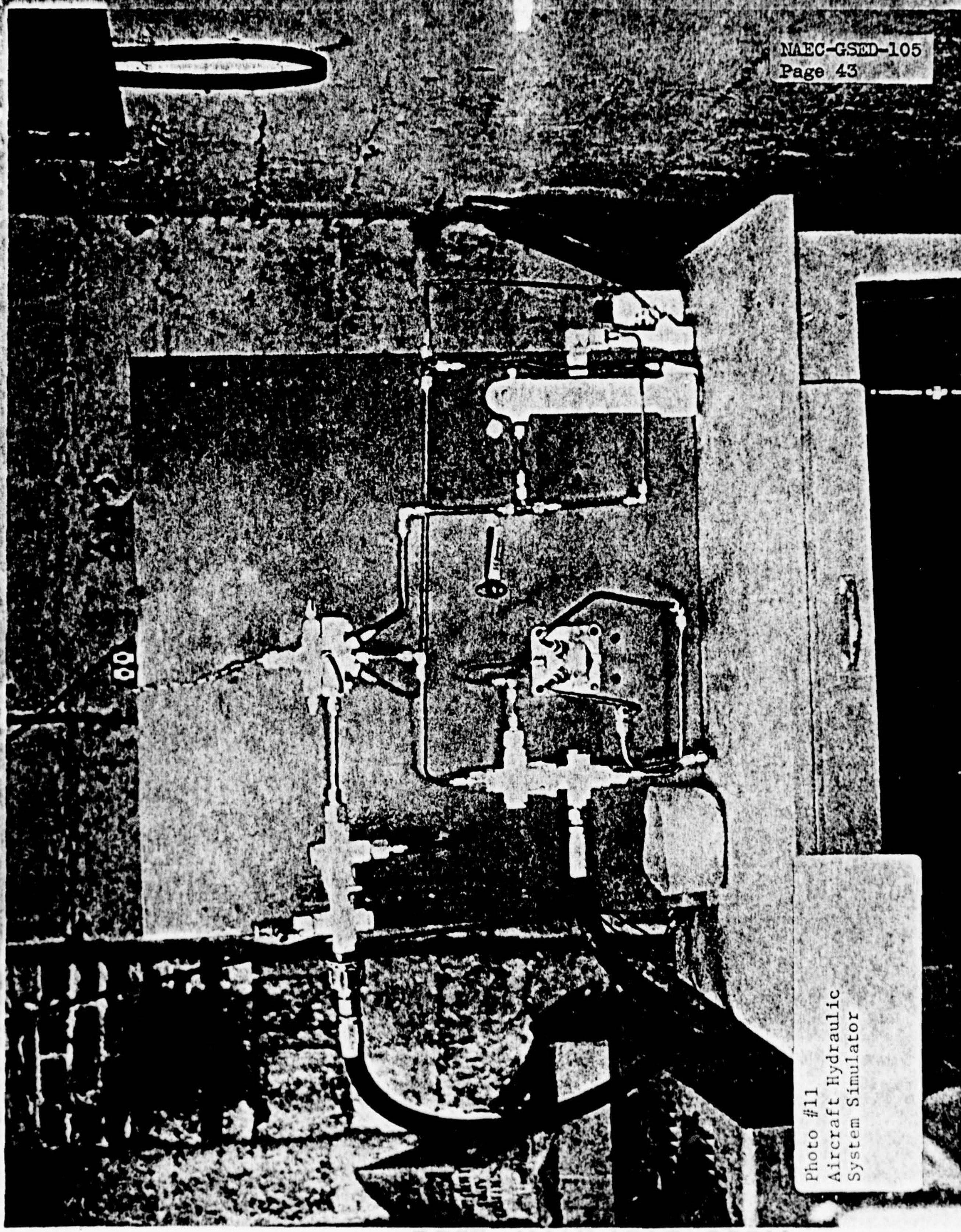


Photo #11
Aircraft Hydraulic
System Simulator

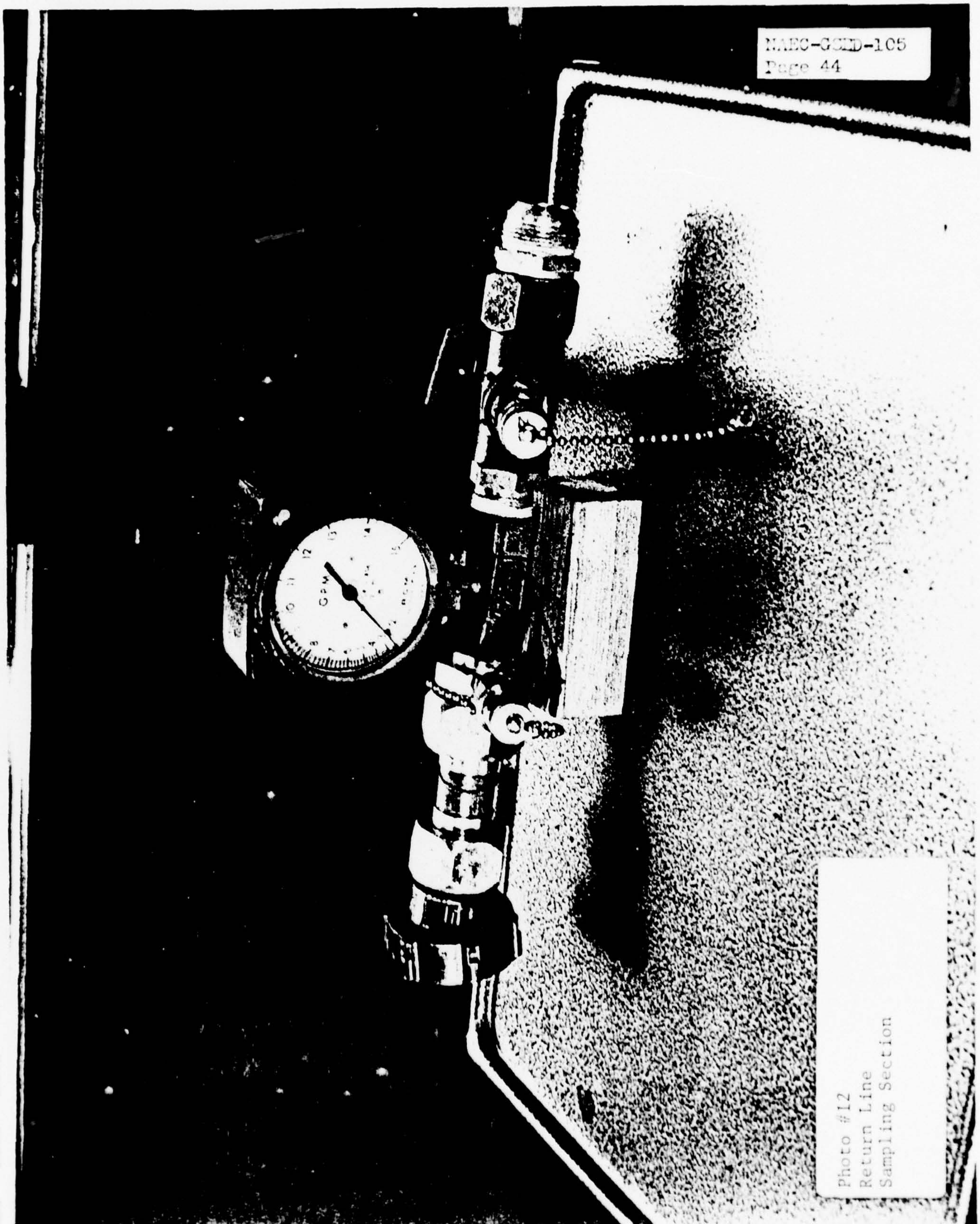


Photo #12
Return Line
Sampling Section

8.7.3. USE OF THE FIELD SIMULATOR. The field simulator functioned in a satisfactory manner, but did not provide a useful check of the in-line contamination monitor. Approximately 7 to 9 gallons per minute flow was provided to the field simulator, but it circulated very quickly through the 3 micron filter of the AHT 64 so that the contamination monitor was always looking at clean fluid, and the clean-up process could not be observed. When the opportunity presented itself to conduct tests with actual aircraft, use of the field simulator was discontinued. The field simulator was very helpful in establishing the requirements for the return line sampling section.

8.7.4. DESIGN OF THE CONTAMINATION MONITOR SAMPLING SECTION. The contamination monitor sampling section has quick disconnect fittings on either end so that it can be quickly connected to a ground hydraulic test cart and the aircraft return line hose. These fittings are AEROQUIP part numbers 145-S5-20D and 014519-S4-20D. A flowmeter is provided to insure that adequate return flow is coming from the aircraft to prevent recirculation of the monitored fluid. On either side of the flowmeter 1/4 inch quick disconnect fittings are provided for hose connections to and from the contamination monitor. The sampling section functioned satisfactorily, but was constructed by assembling standard "off-the-shelf" connectors. It is cumbersome and the design could be simplified. Also, turbulent flow of the hydraulic fluid past the contamination monitor inlet is required to insure that the flow to the contamination monitor is representative of the return flow from the aircraft. Close attention should be paid to this aspect of design.

8.7.5. CONCLUSIONS.

a. Test of the contamination monitor with actual aircraft is preferable to test using a field simulator.

b. The sampling section of the contamination monitor is adequate, but the design could be improved. A study of the effects of turbulent versul non-turbulent flow would be helpful for establishing design parameters for the sampling section.

8.7.6. RECOMMENDATIONS.

a. Study the effects of turbulent versus non-turbulent flow on the performance of in-line contamination monitors.

b. Improve the design of the sampling section of the contamination monitor.

8.8 Preparation of Procurement Specification

8.8.1 General - Although there are equipments available which could be used for measuring particulate contamination in aircraft hydraulic systems, none of them are ideally suited to the organizational maintenance task of insuring system cleanliness. For this task the flight line mechanic needs a reliable indicator which gives an uncomplicated measurement of clean or dirty. It should be easy to use, consistent in its measurement, and sufficiently durable to withstand the rigors of normal usage. Finally, the cost of the device should not be excessive. The testing which was done under this contract was for the purpose of determining those characteristics of a monitoring device which must be clearly defined in a procurement specification if these objectives are to be achieved. A device like this is electro-mechanical in nature, but is unique in that no equipments exactly like this have ever been procured previously.

8.8.2 Work Accomplished - To prepare the procurement specification, four conferences were held at the Naval Air Engineering Center.

a. On August 7, 1975 Messrs. P. Senholzi, D. Mayer, J. Merino, H. Ott and J. Coyle met to discuss the general requirements of the specification. It was agreed to follow the general format of specification AV 4000. At a later date Purchase Description Number 27B for a Frequency Changer was selected as a more appropriate format. MIL-T-21200 Class 2 was chosen to be the guide for environmental requirements.

b. On December 15, 1975 the first draft of the specification was reviewed, several changes were agreed upon, and incorporated into the specification.

c. On March 3, 1976 the maintainability and reliability portions of the procurement specification were subjected to further review and maintainability and reliability design parameters were agreed upon, and the environmental test specification was changed to MIL-STD-810. A second draft of the specification was prepared.

d. On June 14, 1976 the second draft of the specification was reviewed, and with the assistance of Mr. D. Mayer the specification took final form. The final draft of the specification is Appendix A of this report.

8.8.3 Discussion - In their present form there is strong doubt that any of the equipments tested can meet the procurement specification

requirements for a contamination monitor. Both the Micro-Scan 2 and the HIAC PC 120 reveal performance shortcomings which must be overcome before they are satisfactory. They must be packaged to meet the specification requirements, and redesigned for the environmental test requirements. Either instrument has a potential for fulfilling these requirements. Because of the uniqueness of the contamination monitor some of the specified requirements are only best estimates. Some leeway may be possible, and actual test and usage will be necessary to confirm the accuracy of these first requirements. An update of the specification should be made after a reasonable period of service experience.

8.8.4 Conclusion - Specification tests and reliability and maintainability design parameters are based on best judgement and have been selected from requirements of reasonably similar equipments. A contamination monitor is a unique equipment, not falling into any existing category.

8.8.5 Recommendation - After a reasonable period of service usage, verify validity of tests specified in the procurement specification, and in reliability and maintainability design parameters.

9. REFERENCES

a. J. J. Coyle, "A Study of Hydraulic System Wear in Navy A7E Aircraft", Mechanical Engineering Department Report, Villanova University, Villanova, Pa. 19085, March 1974

b. E. McAssey, "Micro-Scan Test Program", Mechanical Engineering Department Report, Villanova University, Villanova, Pa. 19085, November 1972.

c. ANSI B93.28-1973, "Method for Calibration of Liquid Automatic Particle Counters Using 'AC' Fine Test Dust", American National Standards Institute, 1430 Broadway, New York, N. Y. 10018.

d. J. J. Coyle and J. E. Fountaine, "Detection and Removal of Water from MIL-H-5606B Hydraulic Fluid", Mechanical Engineering Department Report, Villanova University, Villanova, Pa. 19085, December 1972.

e. J. J. Coyle, "Characteristics of MIL-H-5606B Hudraulic Fluid in Navy Operating Aircraft and Support Equipment", Mechanical Engineering Department Report, Villanova University, Villanova, Pa. 19085, December 1972.

f. L. E. Bensch, "Survey on Calibration of Automatic Particle Counters in the 1 to 10 Micrometer Range", Paper No. P75-13, Fluid Power Research Center, Oklahoma State University, Stillwater, Oklahoma 74074, 1975.

RUN No	TOTAL DIRT mg/l	MICRO SCAN	HIAC - Counts/ml PARTICLE SIZE - micrometers >10	>13	>16.5	>19.4	>22	>43	TTMC - Count/ml >5	>10	>25	>50	>100	GRAVI-METRIC mg/l
1	0	0.7	3544	1920	480	180	52	0	18666	3243	451	52	20	12.0
2	1	4	3323	1800	520	156	60	0	23600	2699	236	22	8	12.4
3	3	10	3876	2100	680	230	90	4	19060	2465	220	26	7	10.4
4	5	26	4523	2450	940	400	190	16	22900	3604	521	37	7	12.4
5	7	44/32*	4984	2700	1020	460	230	20	22700	3480	545	53	13	9.1
6	11	51/28*	5353	2900	1080	540	280	20	25500	4444	670	49	11	17.8

* READINGS BEFORE/AFTER GRAVIMETRIC SAMPLING.

TABLE 2 — TEST DATA OF JAN. 6, 1976.

RUN	TOTAL	MICRO	HIAC - counts/ml						TTMC counts/ml					GRAVI-
NO.	DIRT	SCAN	PARTICLE SIZE - micrometers											METRIC
	mg/l		>6.5	>10	>15	>20	>25	>50	>5	>10	>25	>50	>100	mg/l
1	0	5.2	220	64	24	10	4	0	685	132	50	6	2	3.0
2	1	30	680	250	116	20	12	0	2282	300	69	8	2	0.5
3	2	60	1260	410	200	56	28	4	2372	391	92	9	3	1.5
4	3	70	1680	520	250	62	32	2	3415	468	118	12	3	3.3
5	4	74	1900	640	320	72	36	4	3398	524	141	12	2	5.9
6	6	87	2600	940	470	104	44	4	5135	863	180	17	5	1.9
7	8	94	3200	1200	580	124	60	4	6909	1297	256	19	5	3.0

TABLE 3 – TEST DATA OF FEB. 9, 1976.

RUN NO.	TOTAL DIRT mg/l	MICRO SCAN	HIAC COUNTS/ml → PARTICLE SIZE - micrometers >6.5	>7.5	>10	>15	>20		TMC COUNTS/ml → >5	>10	>25	>50		GRAVIMETRIC mg/l
1	0	5.2	64	48	20	0	0		1454	111	39	9		0.1
2	0.5	10	300	200	100	44	12		1303	160	40	10		0.03
3	1.5	10	620	390	160	70	12		1832	245	63	14		0.04
4	2.0	12	880	600	250	110	16		2212	349	69	12		1.3
5	2.5	14	1280	760	320	140	24		2679	429	70	12		1.2
6	3.0	21	1440	880	390	164	30		2673	464	78	11		0.8
7	4.0	19	1840	1160	520	190	42		3387	705	100	12		1.3
8	5.0	36	2300	1440	600	240	40		3862	830	145	18		2.1

TABLE 4 - TEST DATA OF MAR. 4, 1976.

Run No.	Total Dirt mg/l	Micro Scan	HIAC - Counts/ml? → Particle Size - micrometers >6	>10	>15	>20	>25		TMC → >6	>10	>15	>25	>50
1	0	1.6	5200	2100	320	60	12		1370	115	80	26	2
2	0.5	2.7	4900	2000	320	64	16		1879	132	102	30	3
3	1.0	3.2	5100	2100	360	76	24		2300	176	142	38	4
4	1.5	4.2	5100	2200	410	92	32		②				
5	2.0	16 ①	5200	2350	460	96	40		②				
6	2.5	18	5500	2300	420	104	36		3416	277	205	64	6
7	3.0	18	5800	2400	440	112	40		3653	387	320	89	7
8	3.5	20	5500	2300	450	108	36		4217	584	493	130	10
9	4.0	18	5500	2350	460	120	44		4688	817	653	163	13
10	4.5	34	5800	2500	520	136	46		5367	952	764	204	16
11	5.0	40	6000	2700	560	144	52		7375	1276	1022	271	23

① Sensitivity of Micro-Scan adjusted here.

② TMC samples lost when bottles broke during agitation.

TABLE 5 - TEST DATA OF MAY 12, 1976.

AIRCRAFT - US2B BUNO 133054

RUN NO.	MICRO-SCAN	HIAC - Counts/ml PARTICLE SIZE - μm >6	TTMC >6	>10	>15	>25	>50	>100
1	35-60	1100	615	35	29	13	2	0
2	2	1400-800	896	48	35	15	6	3
3	2	700	1035	79	57	17	9	3

MICRO-SCAN FLOW - 500-550 ml/min
HIAC FLOW - 30 ml/min
FLUID TEMPERATURE - 105°F

TABLE 6 - TEST DATA, MAY 4, 1976, NAF WARMINSTER, PA.

TABLE 7

SPECIFICATIONS FOR PARAMETRICS HYGROMETER

MODEL 2000

RANGES: Four ranges in a sequence of 1, 3, 10, 30 units full scale. Standard probe measures dew point range of +20°C to -110°C.

ACCURACY: ±1% or better, referred to full scale, on all four ranges.

POWER SUPPLY: AC -- line voltage 100, 115 or 220 volts 50/60 Hz, less than 1 watt. DC -- Nickel-Cadmium rechargeable battery pack (see Options).

READABILITY: Better than ±0.3% on all four ranges.

OPERATING TEMPERATURE: -10°C to +55°C.

STORAGE TEMPERATURE: -55°C to +75°C.

WARMUP TIME: Less than 5 minutes.

CALIBRATION: Console electronics are self calibrating by a CALIBRATE switch and rear panel potentiometer adjustment. Probe calibration curves are supplied with each sensor.

INPUTS: Six probe input jacks selected by front panel switch.

SHOCK AND VIBRATION: Standard Shipping specifications.

RECORDER OUTPUT: 0-100 mv.

DIMENSIONS: 13"W x 9-3/4"D x 9"H.

PANEL MOUNT CUT OUT DIMENSIONS: 14-1/2"W x 11-1/2"H.

SHIPPING PACKAGE: 15-3/8"W x 14"D x 16"H.

WEIGHT: 6-3/4 pounds net (9 pounds full packed).

CONSTRUCTION: Aluminum Formed Case Panels. Unit is designed for bench, panel or portable use.

FINISH: Black anodized aluminum with clear anodized rim.

TABLE 7 (CONT.)

CALIBRATION: Each sensor provided with individual calibration curve.

DEW POINT RANGE: +20°C to -110°C (+70°F to -170°F). Special high dew point probe calibrated to +60°C offered.

OPERATING PRESSURE: Depends on Fitting.

M12 . . . . 5 microns of Hg to 75 psig
M22 . . . . 5 microns of Hg to 5000 psig
M32 . . . . 3000 psig max.

OPERATING TEMPERATURE: -110°C to +70°C.

STORAGE TEMPERATURE: Maximum of +70°C.

FLOW RATE: Gases . . . . From Static to 5000 cm/sec linear velocity @ 1 atm.
Liquids . . From Static to 5 cm/sec @ density of 1 gm/cc.

RESPONSE TIME: Less than 5 seconds for a 63% step change in moisture content in either wet up or dry down cycle.

TABLE 8

SPECIFICATIONS FOR THE VK-36 HYGROMETER

2.1 ELECTRICAL

1.	AC Power Supply:	100-, 110-, or 220-volts ac, 50 to 60 Hz, 20 watts at maximum output. Unit wired at factory for one of the above voltages.
2.	Range:	0.0000099 to 150 mm Hg (-110^{o}C to +60^{o}C Dew Point)
3.	Accuracy:	Electrical: better than ±1 percent of input signal.
4.	Readability:	Better than ±0.35 percent of input signal.
5.	Operating Temperature:	-20^{o}C to +60^{o}C.
6.	Storage Temperature:	-55^{o}C to +75^{o}C.
7.	Warmup Time:	Meets specified accuracy within 30 minutes of turn-on.
8.	Calibration	Self-calibrating by means of internal calibration signals.
	Intrinsic Safety:	The Model VK-36 Hygrometer has been designed to meet the requirements of the Underwriters Laboratories and the German PTB specifications for an intrinsically safe circuit with respect to the PROBE AND CABLE ONLY in hazardous locations. This design is intended to provide the capability of placing an active probe in Class 1, Groups A, B, C, and D or PTB zones 0, 1, and 2.
	Transportation:	Meets National Safety Transit type of test when packaged as shipped from Veekay, Ltd. One hour vibrations slightly in excess of 1 g. Package Drop: 30 inches on any corner, edge, or flat surface.
	Altitude:	25,000 feet operating, 50,000 feet nonoperating.

TABLE 8 (CONT.)

Inputs:	Maximum of six probes connected to barrier strip at rear.
Signal Outputs:	Continuous on all active points.
Temperature Measurement:	Optional. Maximum of six channels. Temperature is displayed in ^{o}C on digital panel meter from $-20^{o}C$ to $+60^{o}C$.

2.2 MECHANICAL

Dimensions:	6 inches wide by 6 inches high by 23 inches deep (behind rack panel).
Weight:	25 pounds.
Construction:	0.090-inch-thick sheet steel case with aluminum front panel. Plug-in electronics chassis.
Finish:	Black armorhyde case with grey front panel.
Shipping Package:	10½ inches by 9½ inches by 25-3/4 inches.

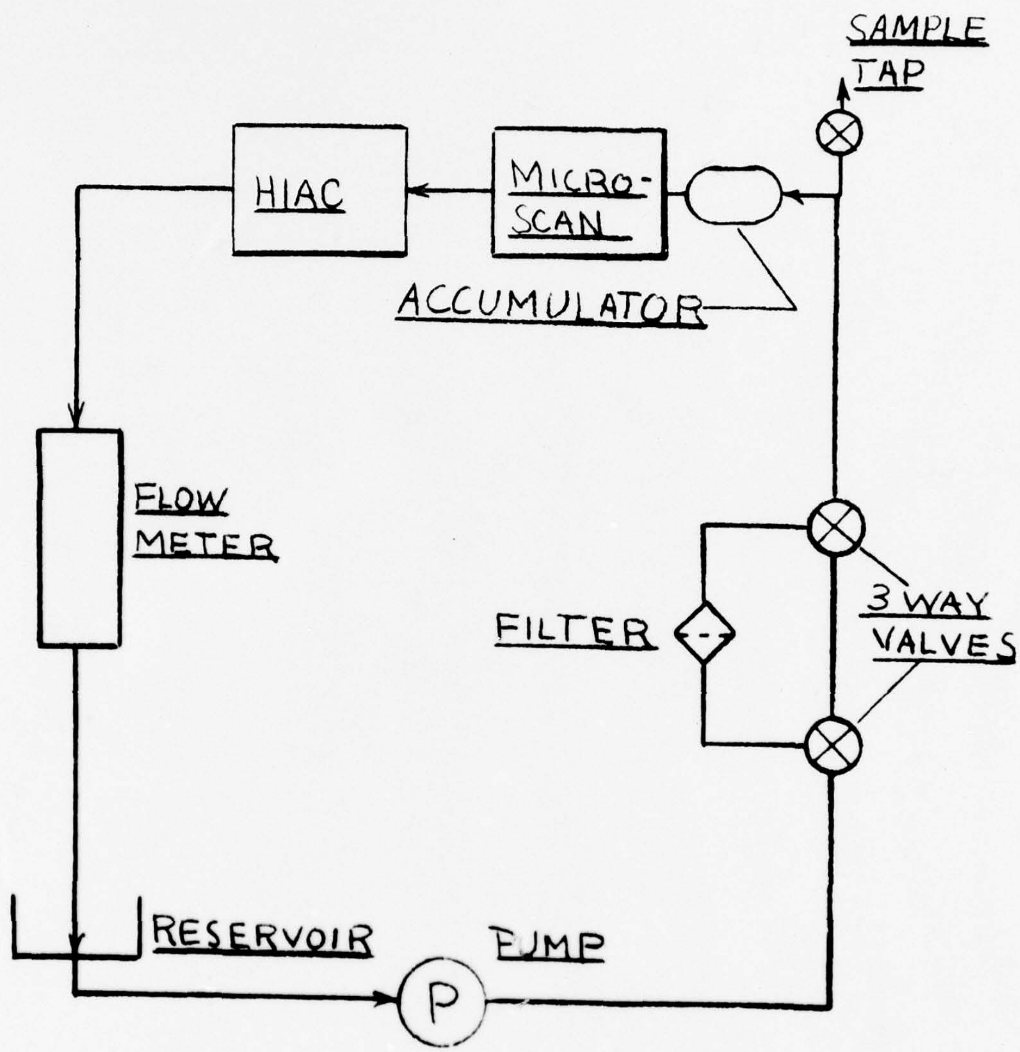


FIGURE 1-TEST SET-UP, JAN. 6, 1976.

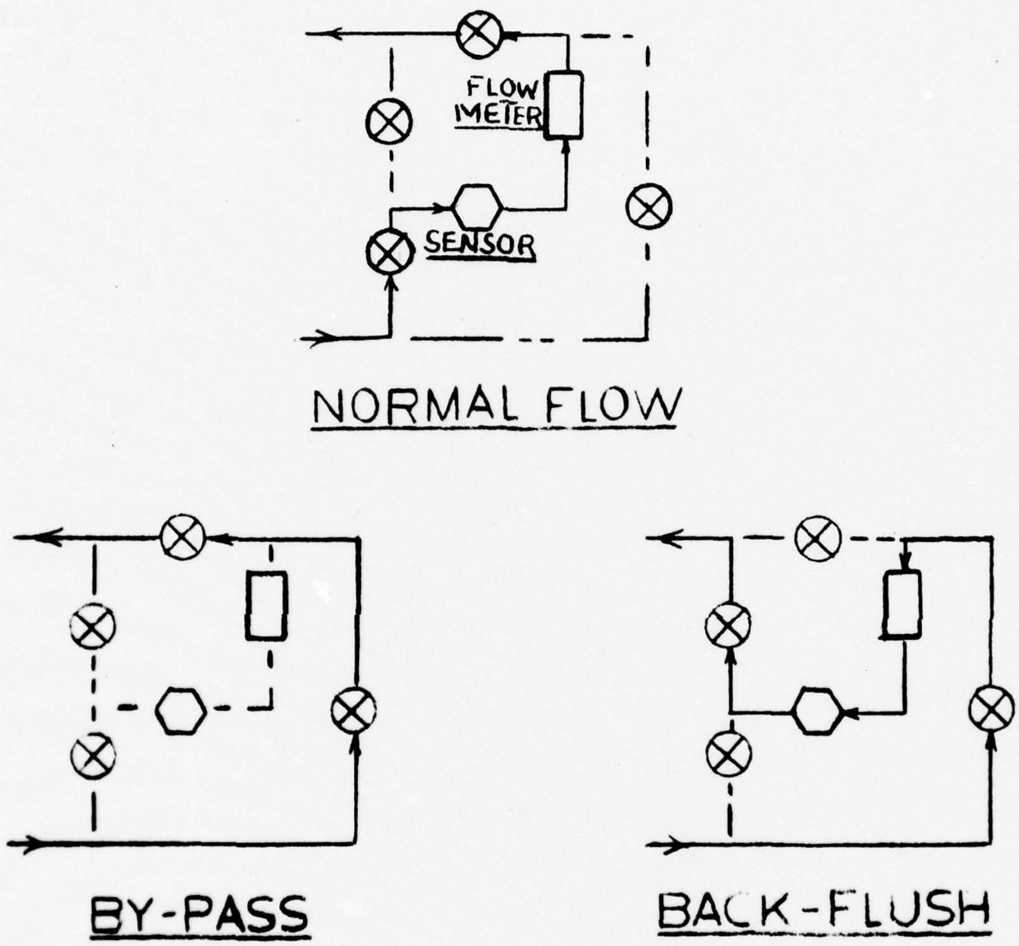


FIGURE 2 - HIAC PIPING.

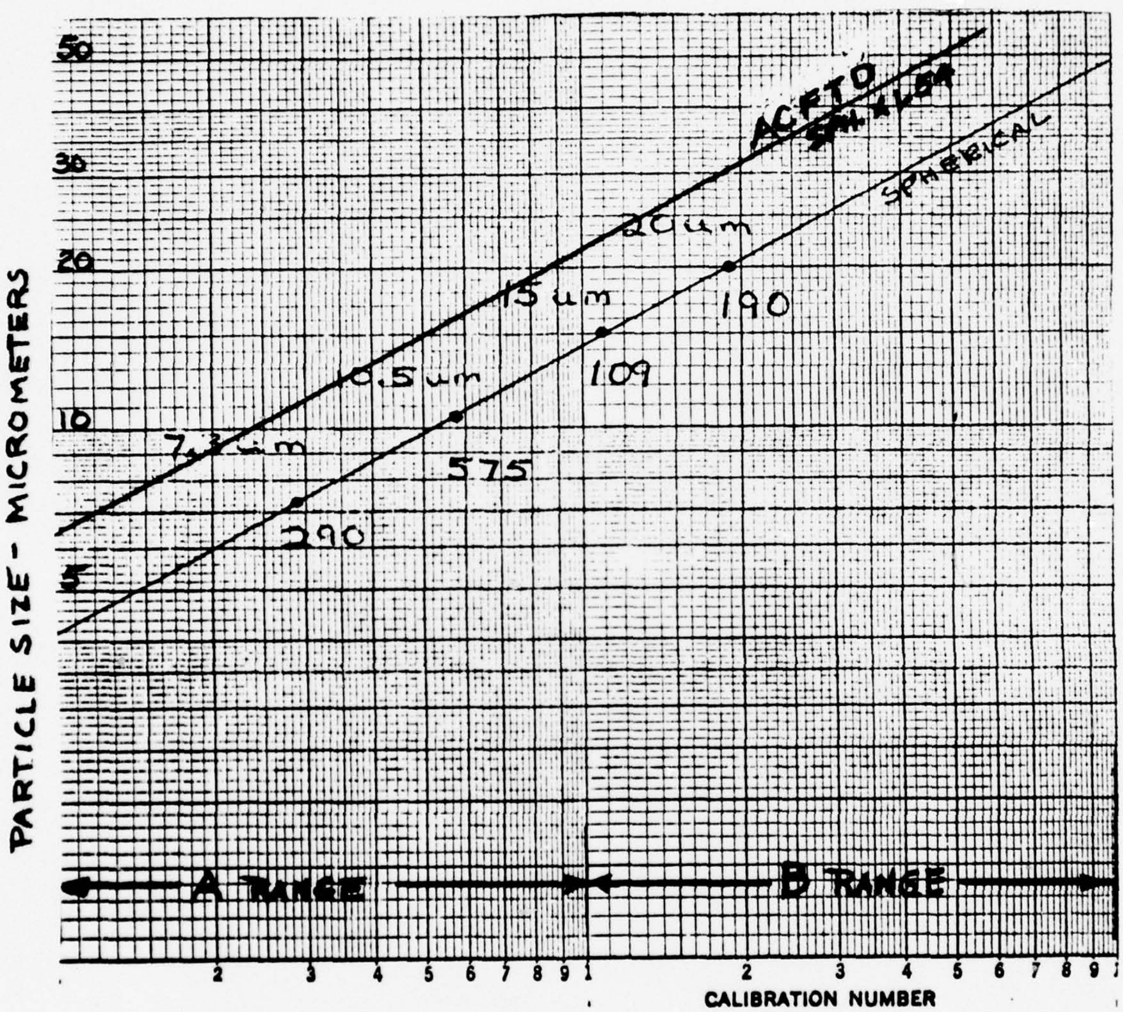


FIGURE 3 - HIAC CALIBRATION CURVE.

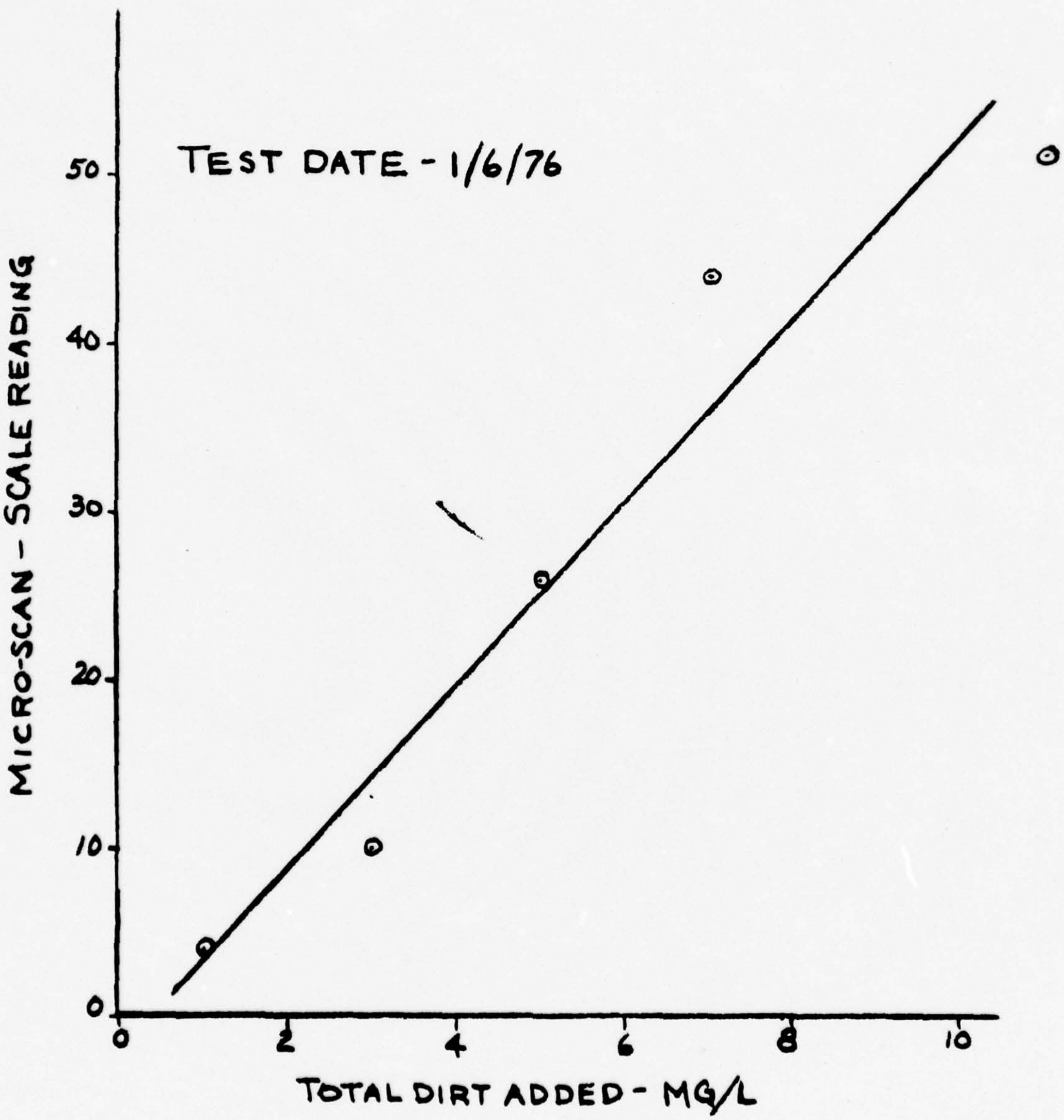


FIGURE 4 - Micro-Scan meter reading vs. Contamination Level, mg/l, 1-6-76.

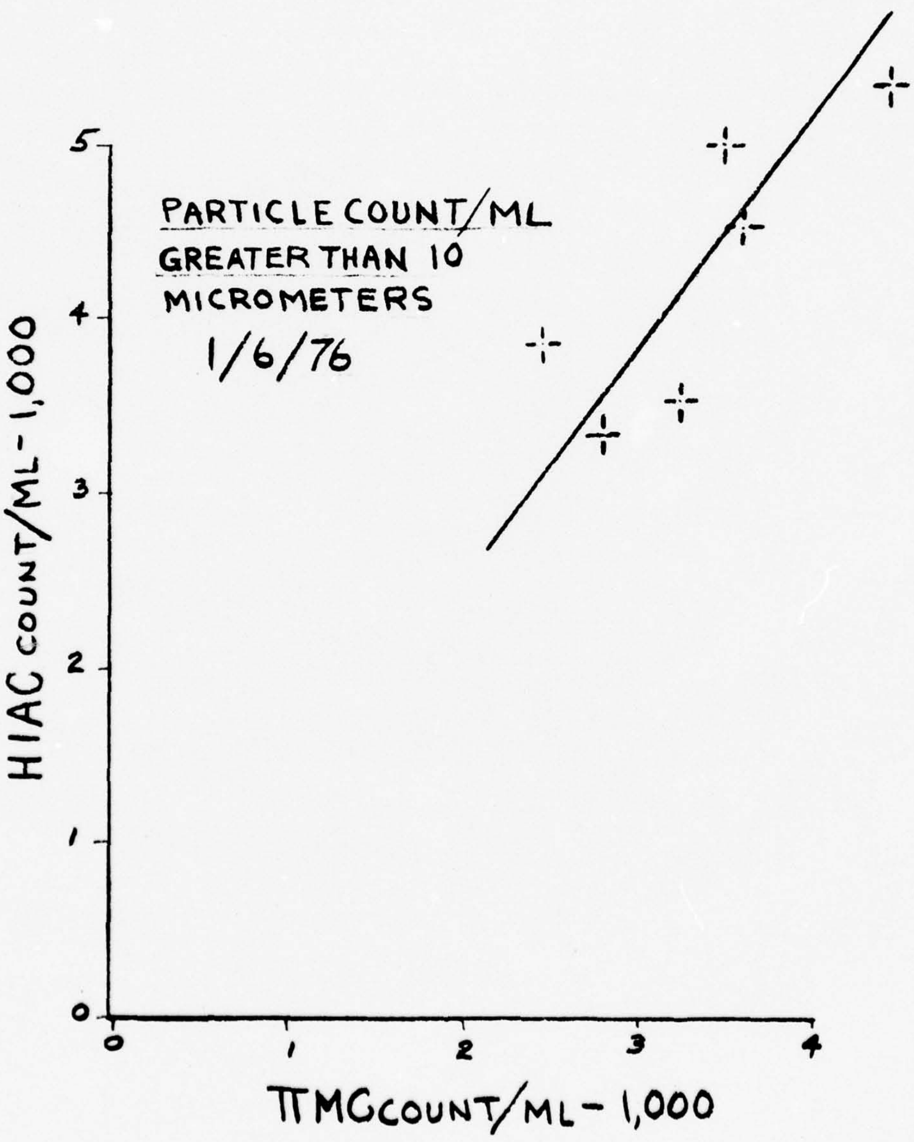


FIGURE 5 - HIAC vs. PIMC, particle count greater than 10 micrometers, 1-6-76.

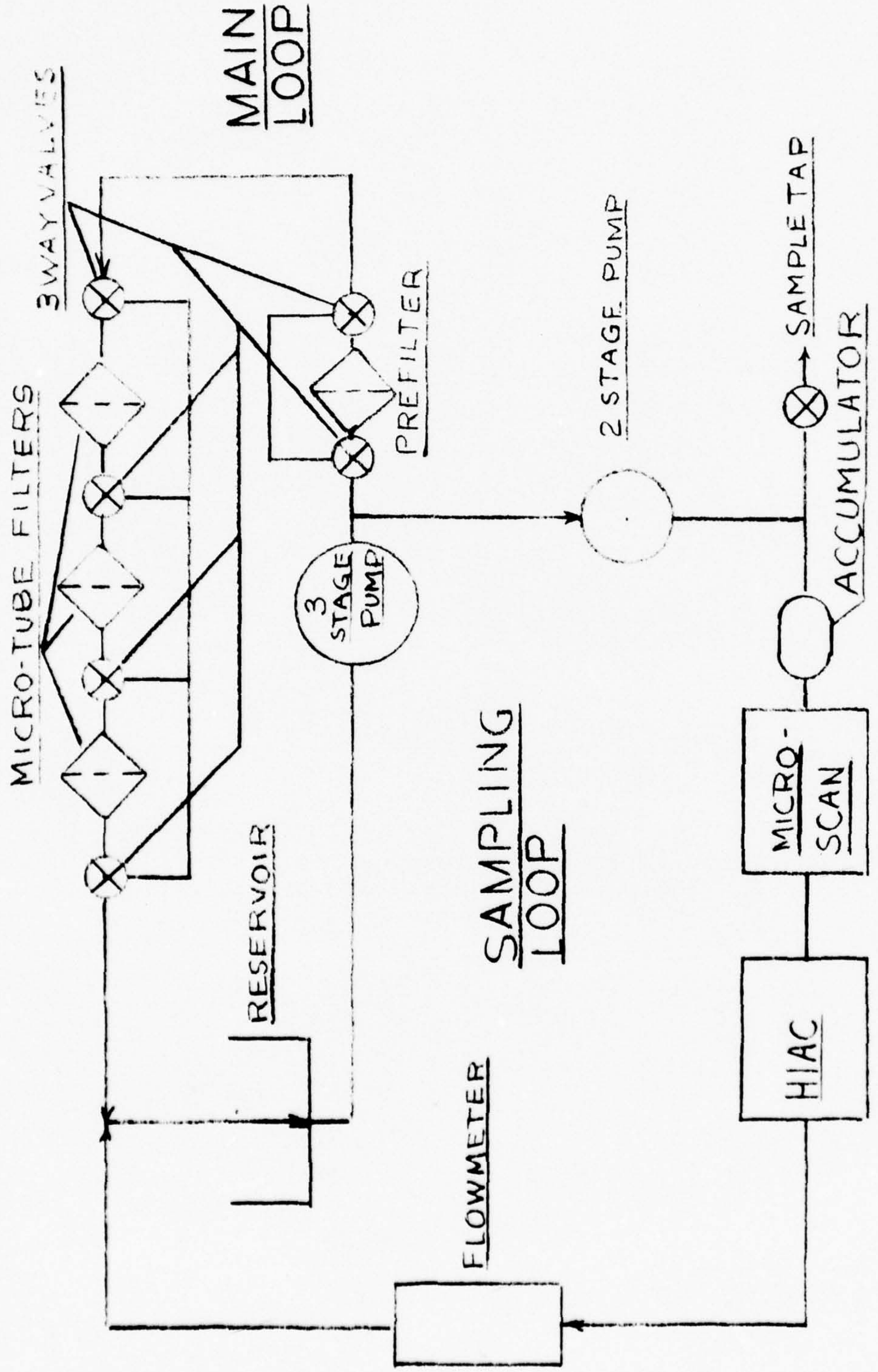


FIGURE 6 - MODIFIED TEST SET-UP.

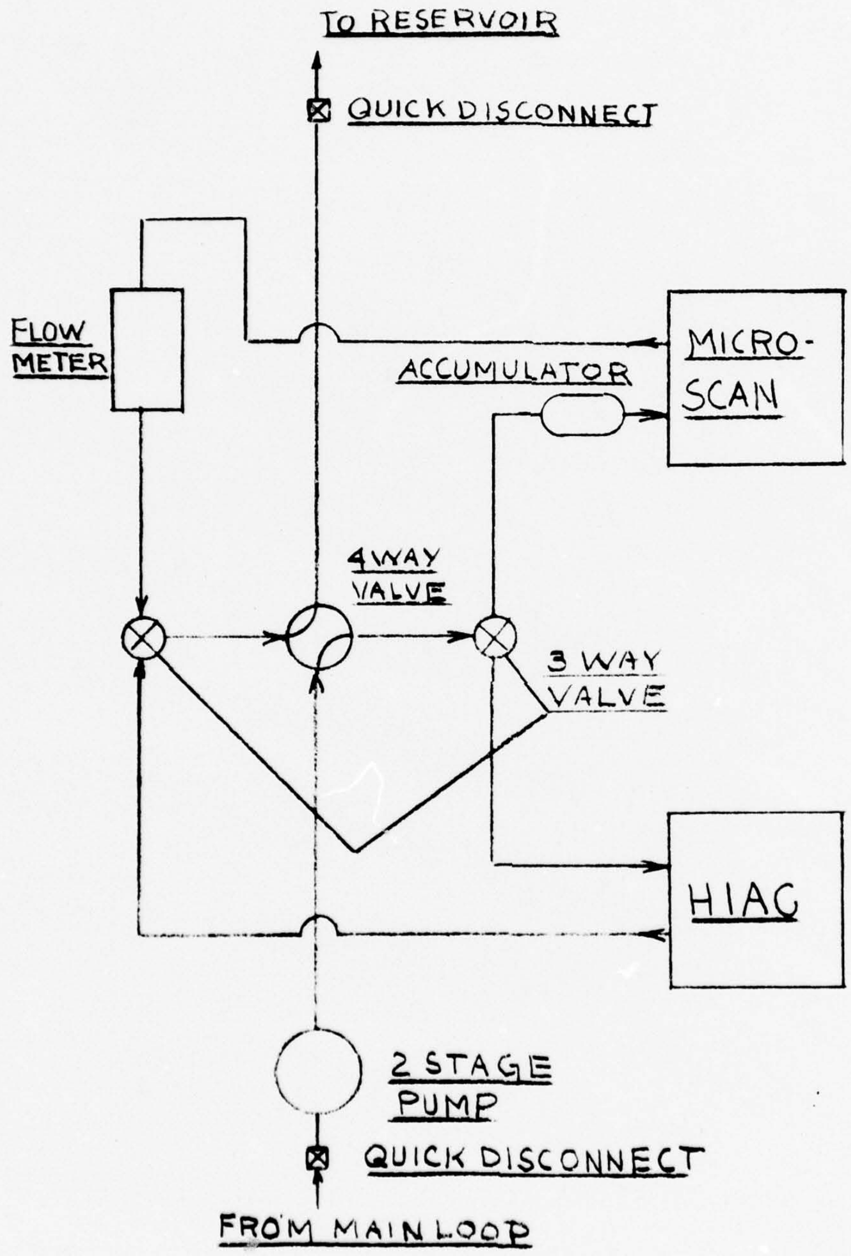


FIGURE 7 - 4 WAY VALVE INSTALLATION.

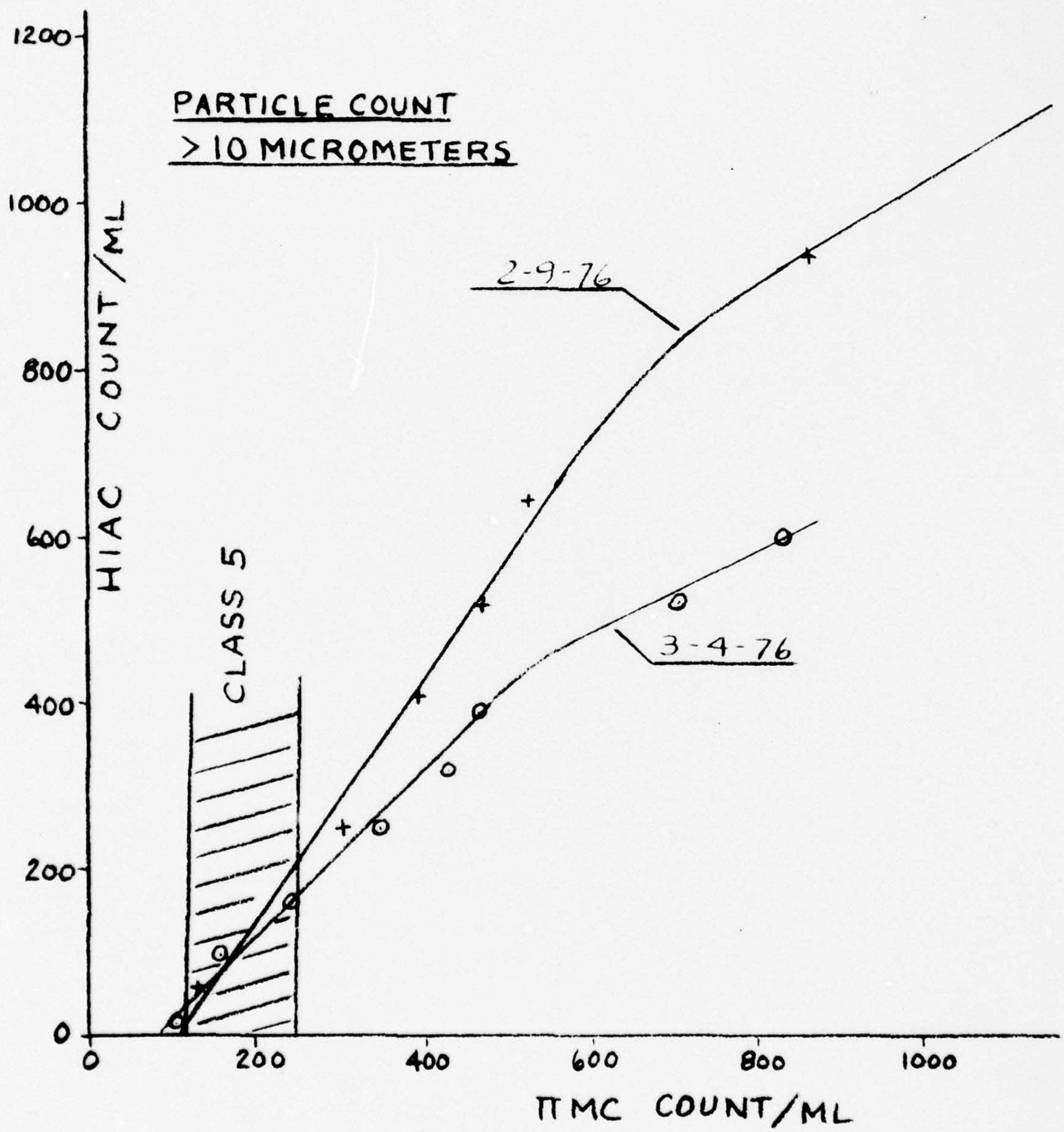


FIGURE 8 - HIAC vs. PIMC, particle count greater than 10 micrometers, 2-9-76 and 3-4-76.

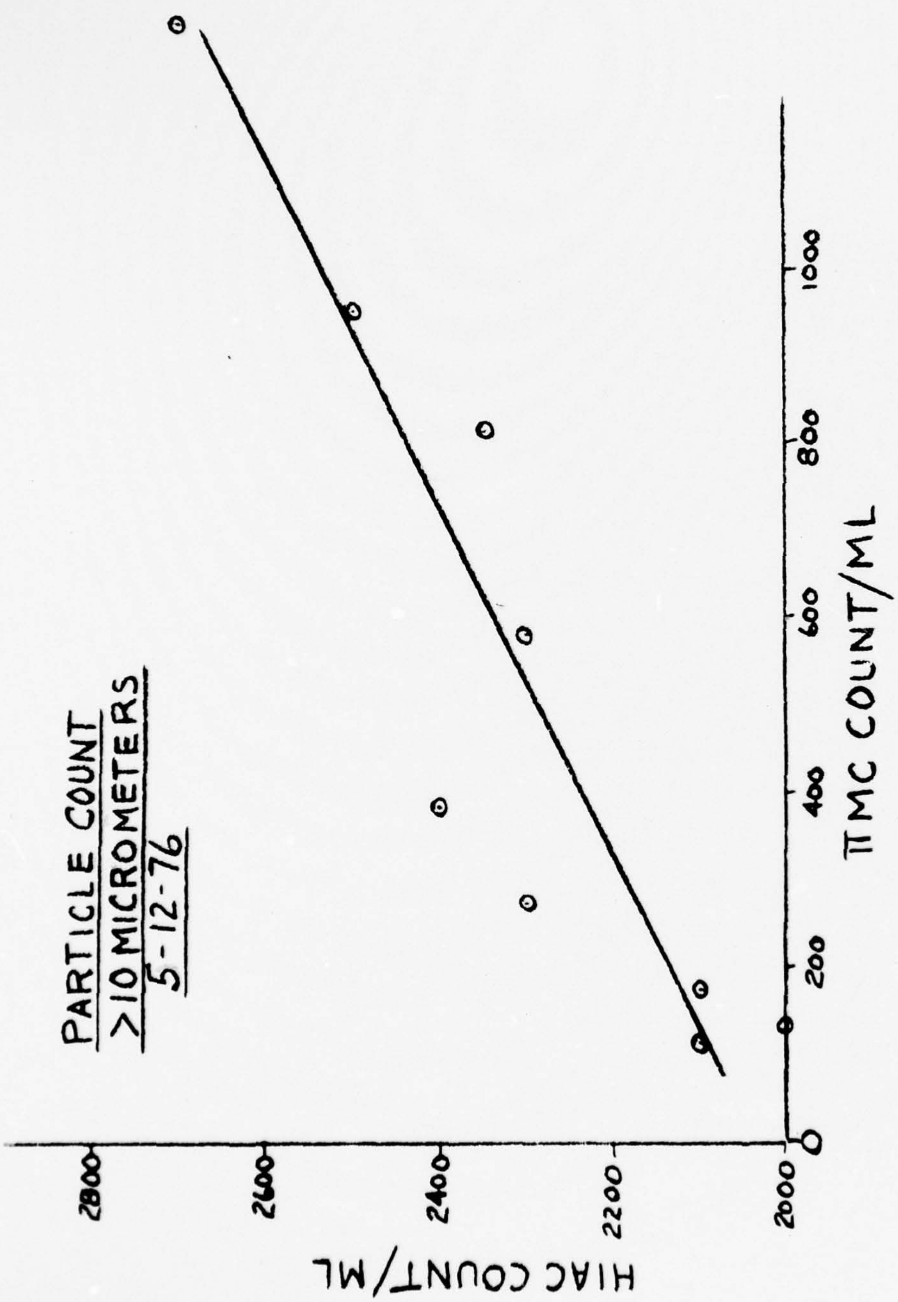


FIGURE 9 - HIAC vs. TTMC, PARTICLE COUNT > 10 MICROMETERS, 5-12-76.

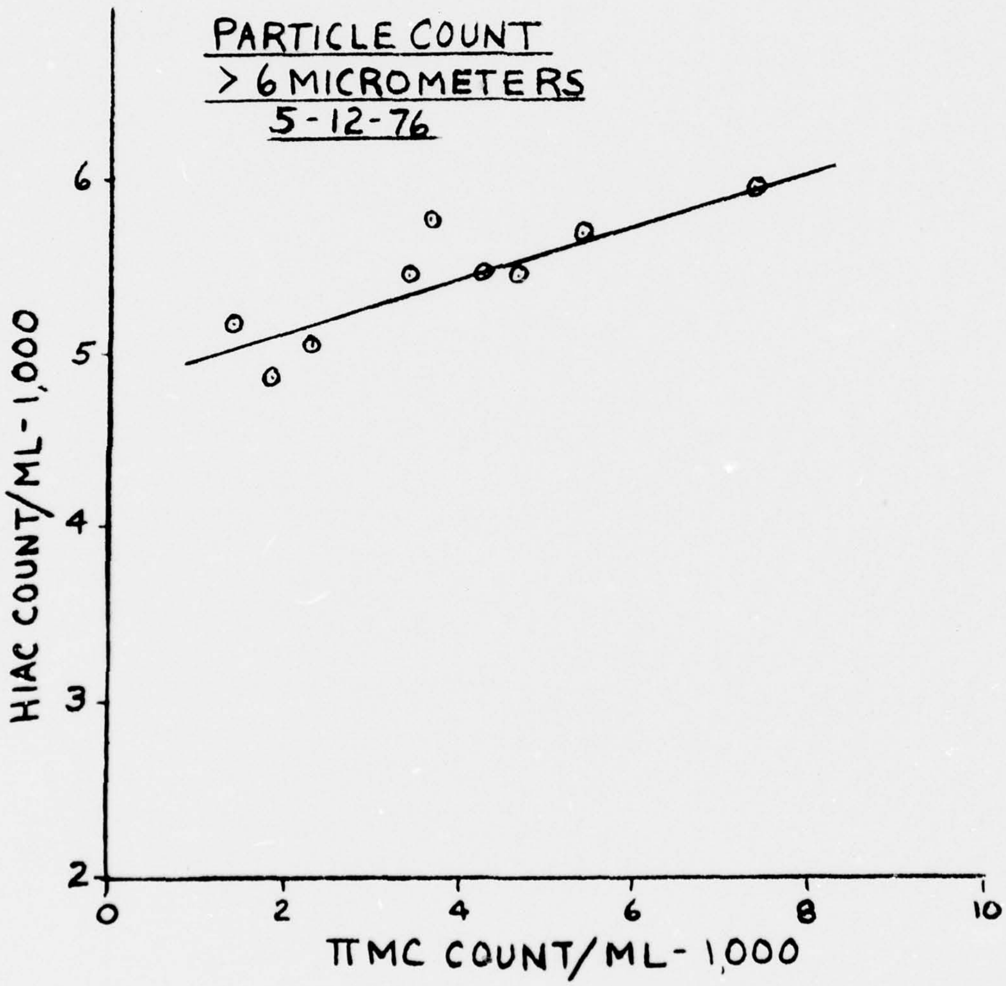


FIGURE 10 - HIAC vs. PIMC, particle count greater than 6 micrometers, 5-12-76.

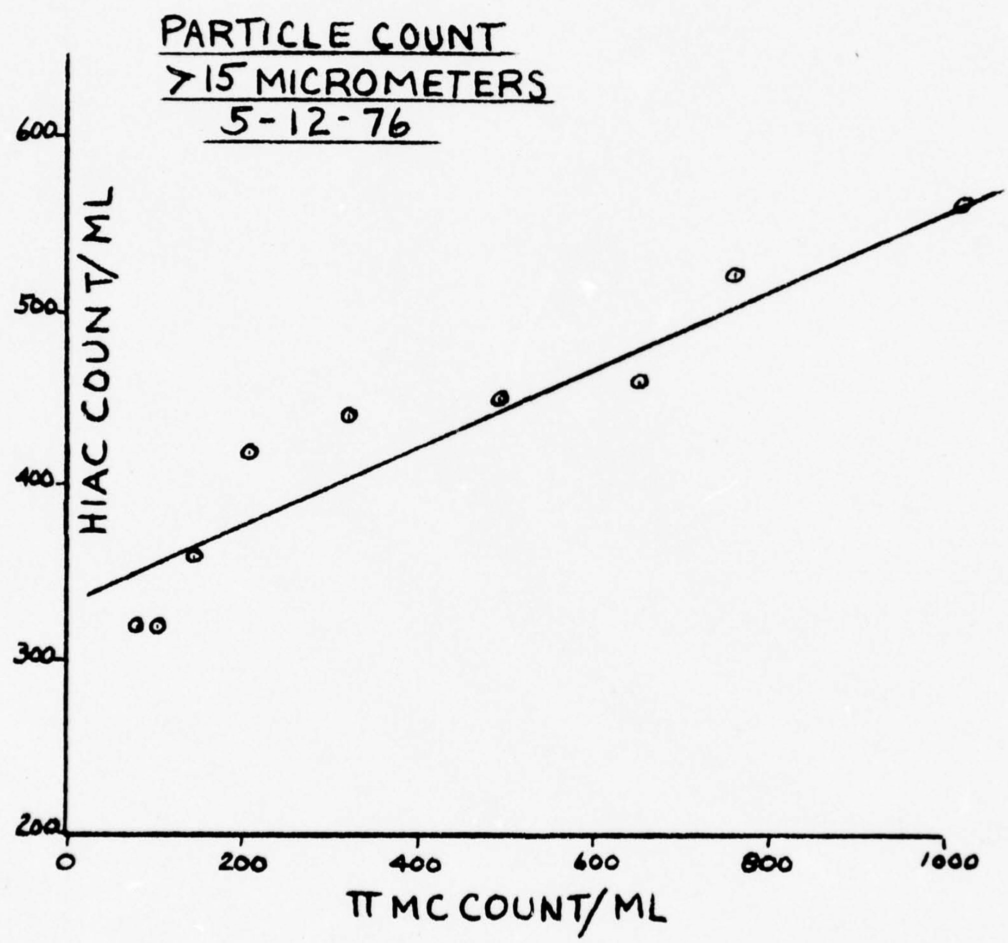


FIGURE 11 - HIAC vs. PIMC, particle count greater than 15 micrometers, 5-12-76.

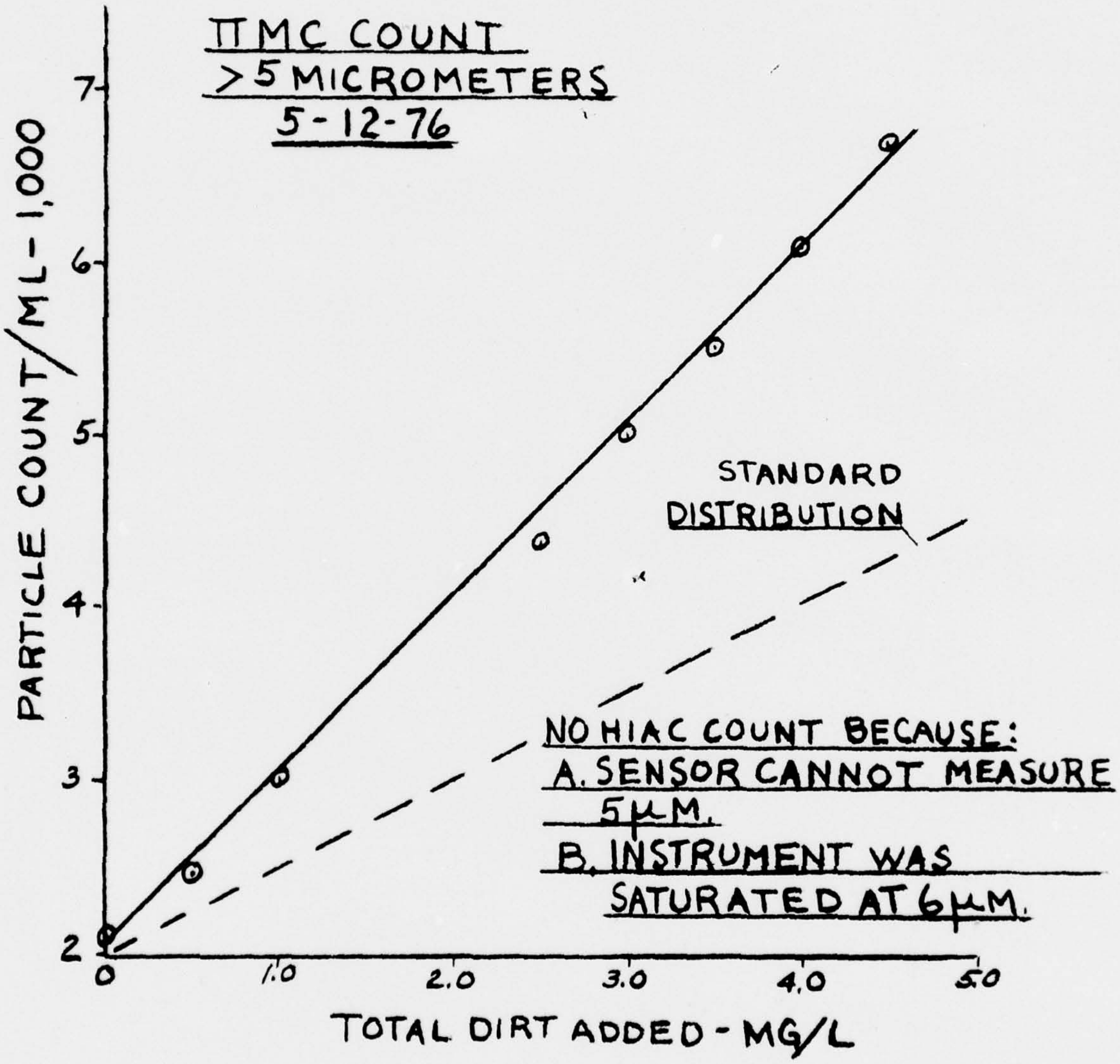


FIGURE 12 - PIMC vs. Contamination Level, mg/l, particle count greater than 5 micrometers, 5-12-76.

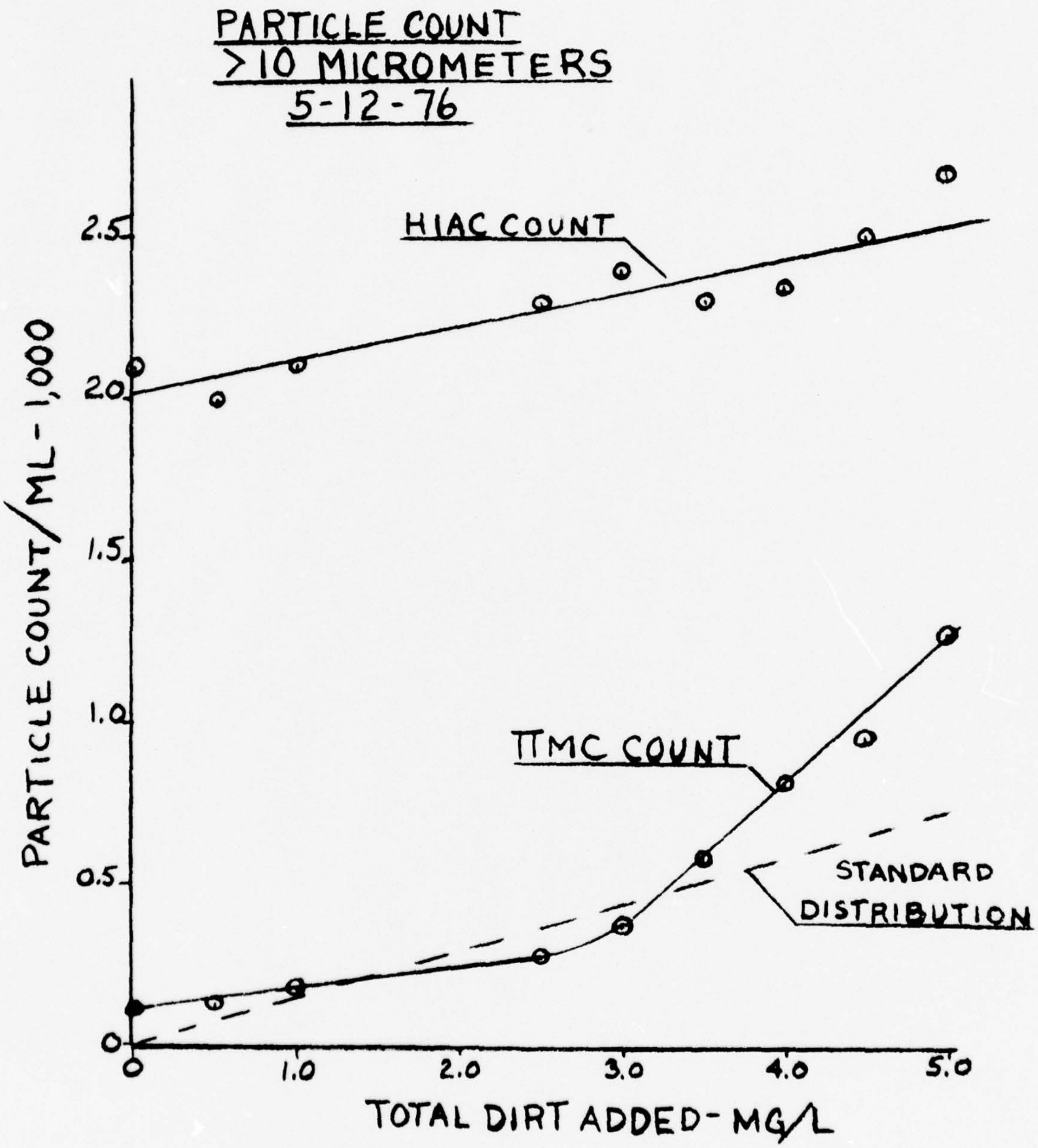


FIGURE 13 - PIMC and HIAC vs. Contamination Level, mg/l, particle count greater than 10 micrometers, 5-12-76.

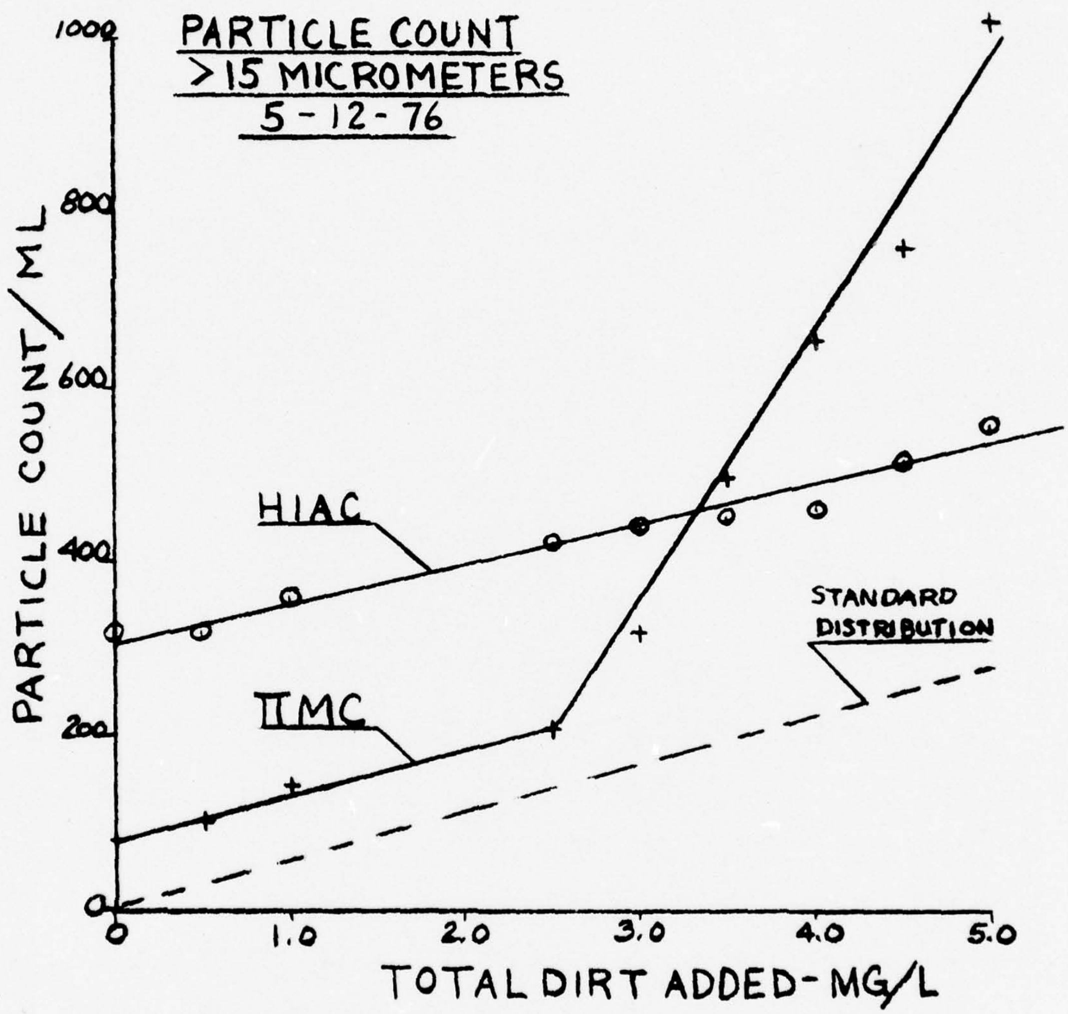


FIGURE 14 - PIMC and HIAC vs. Contamination Level, mg/l, particle count greater than 15 micrometers, 5-12-76.

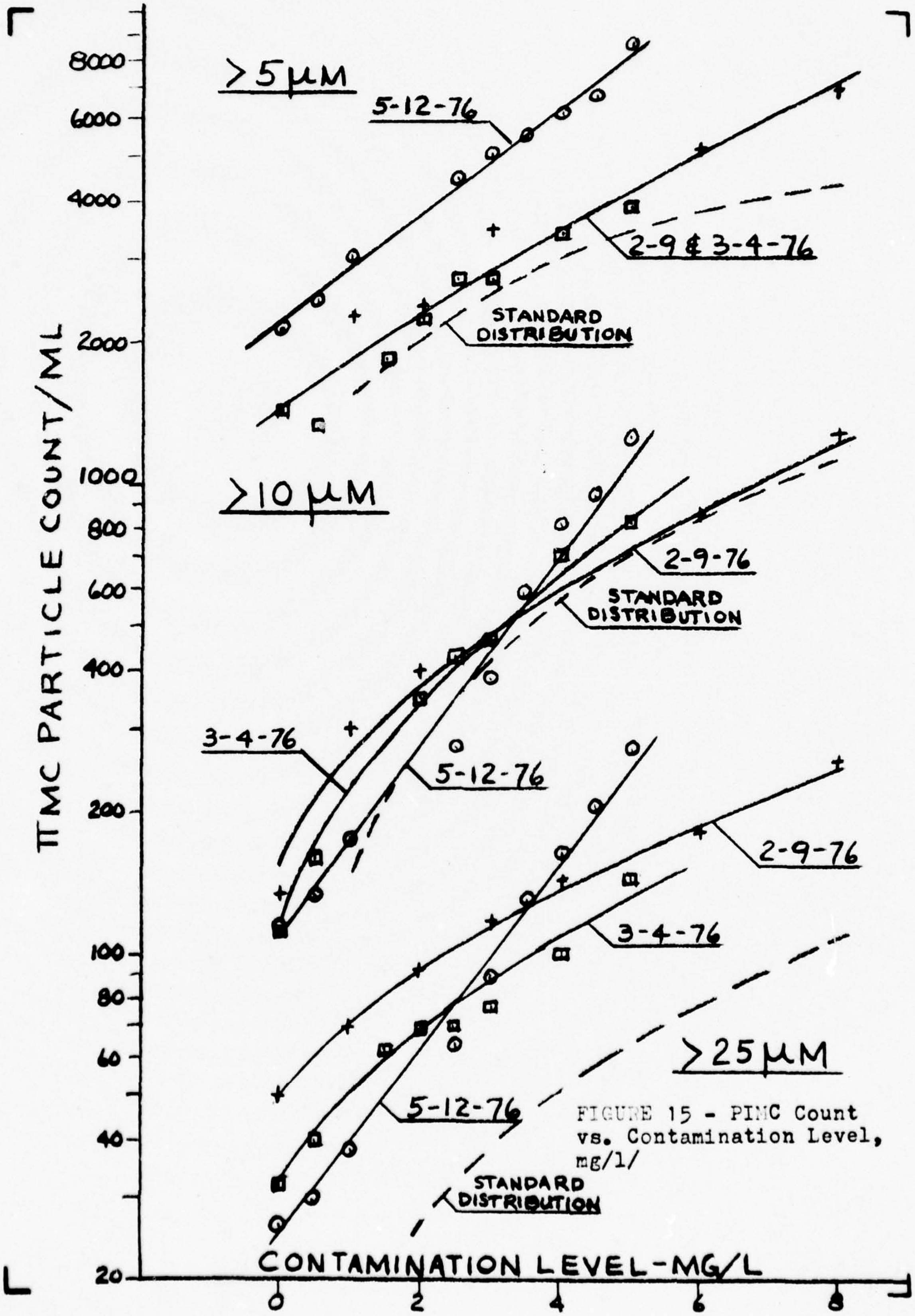


FIGURE 15 - PIMC Count vs. Contamination Level, mg/l/

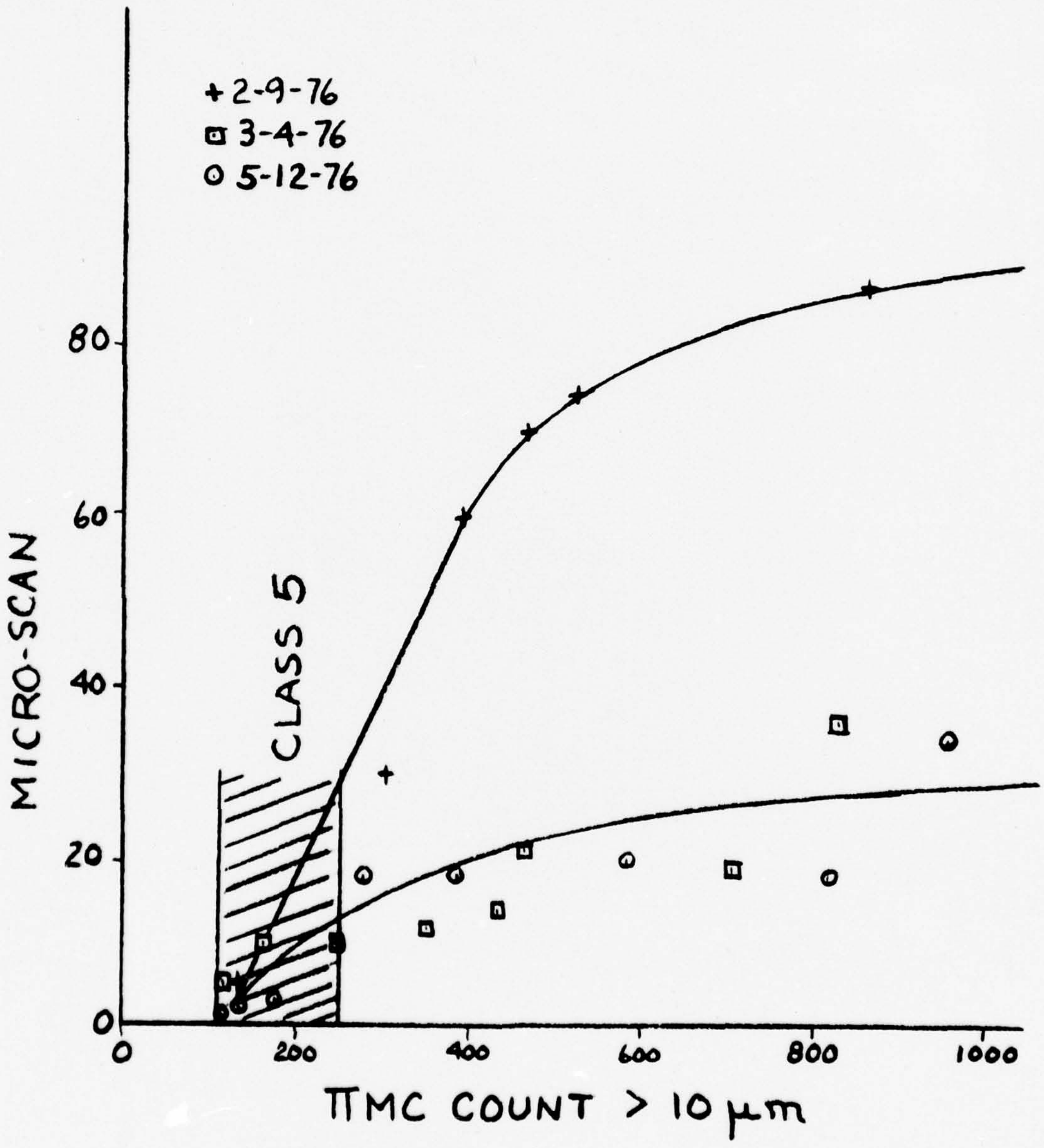


FIGURE 16 - Micro-Scan Meter Reading vs. PIMC Particle Count, greater than 10 micrometers.

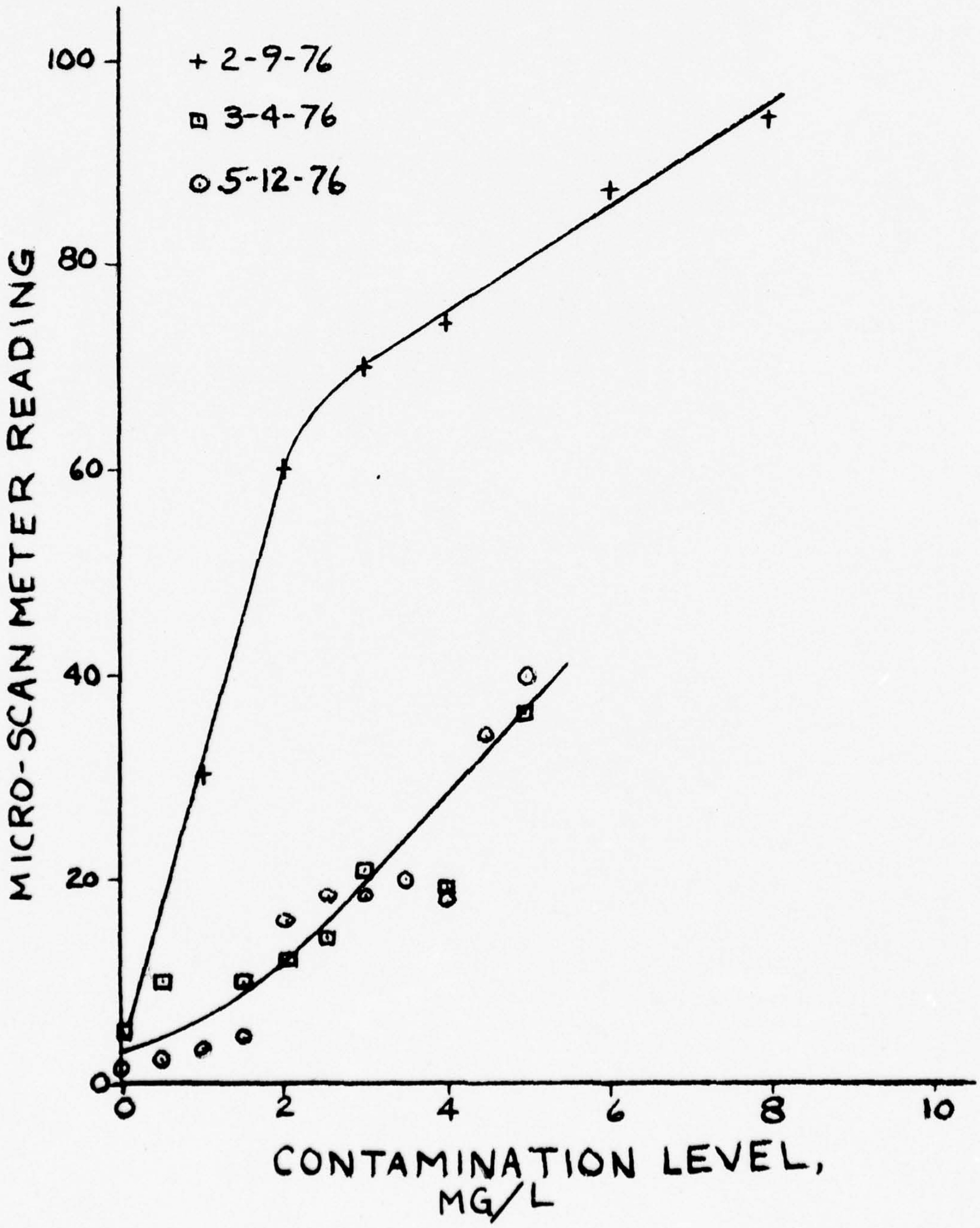


FIGURE 17 - Micro-Scan Meter Reading vs. Contamination Level, mg/l.

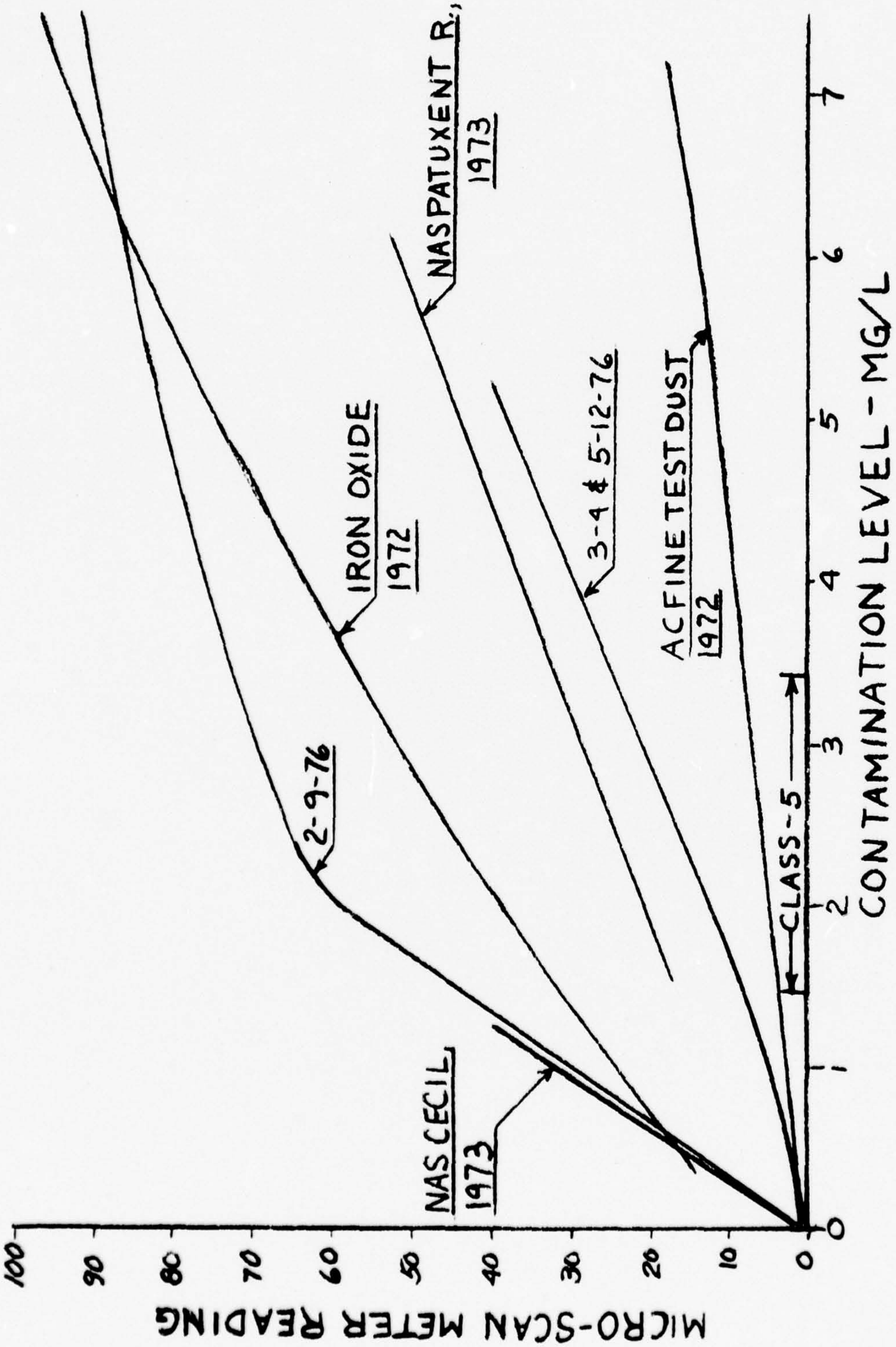


FIGURE 18- COMPARISON WITH PREVIOUS TEST RESULTS.

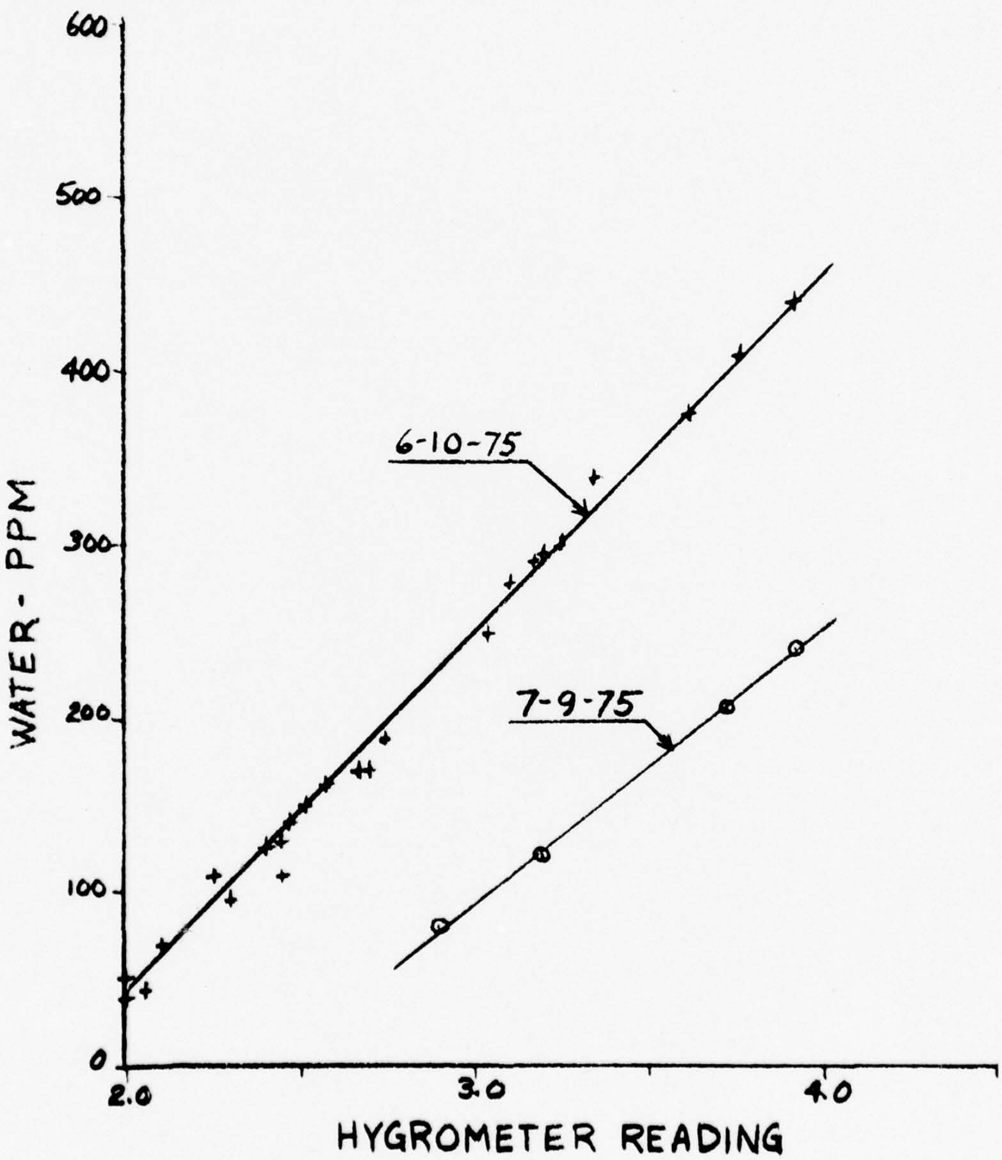


FIGURE 19 - Laboratory Test Results, Panametrics Hygrometer, Model 2000.

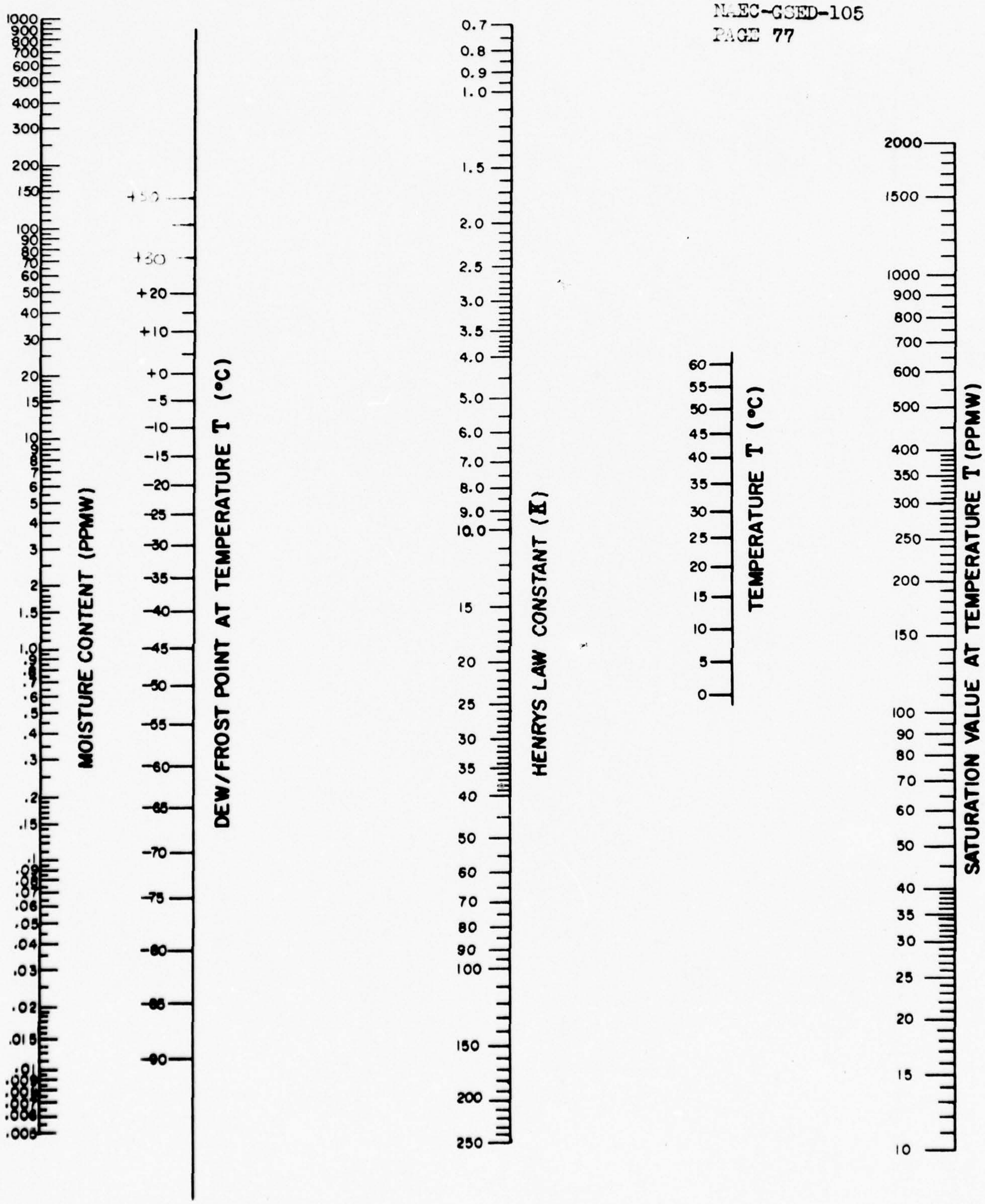


FIGURE 20 - MOISTURE CONTENT FROM MEASURED DEWPOINT

LIQUID SERVICE

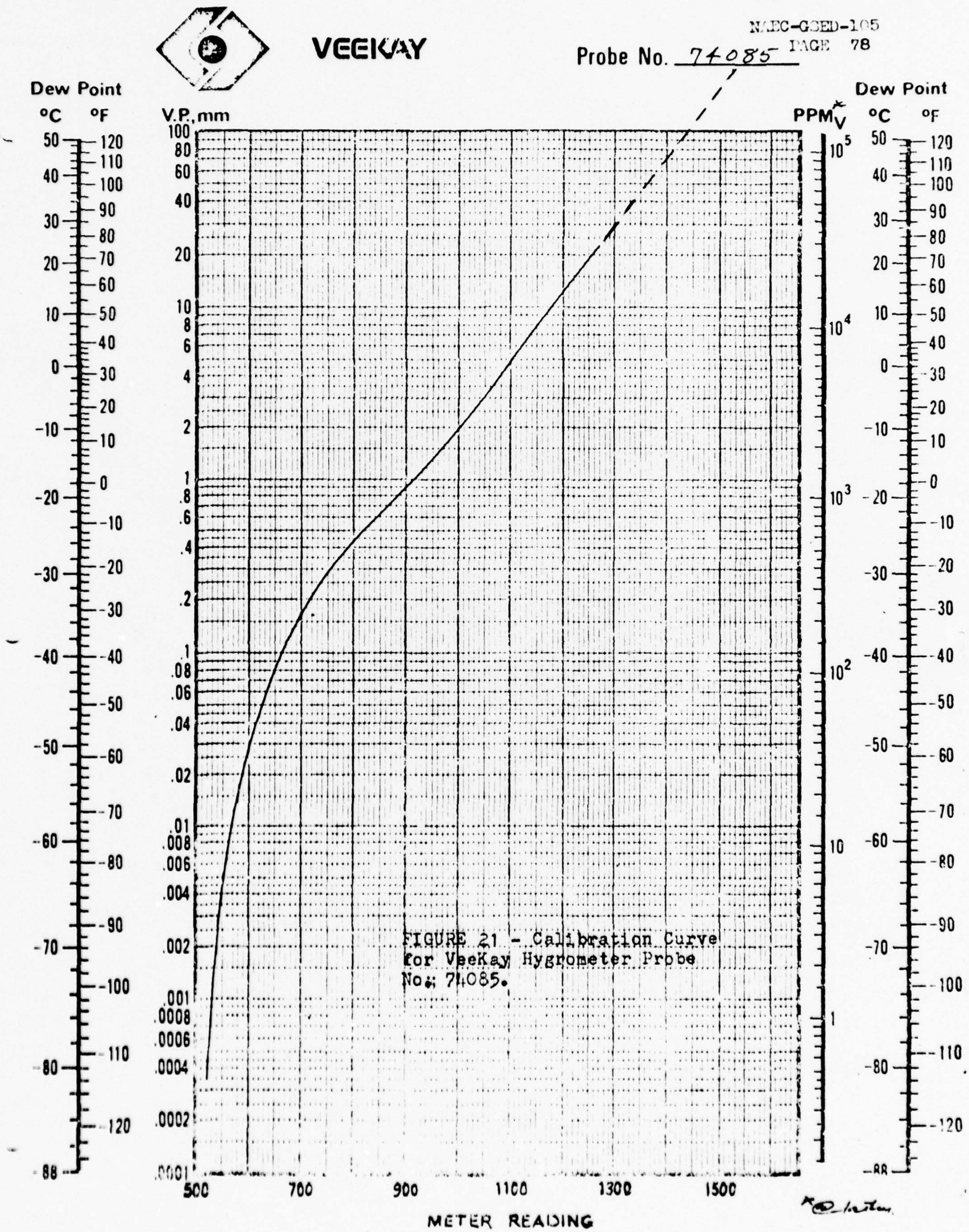


FIGURE 21 - Calibration Curve for VeeKay Hygrometer Probe No. 74085.

95 90

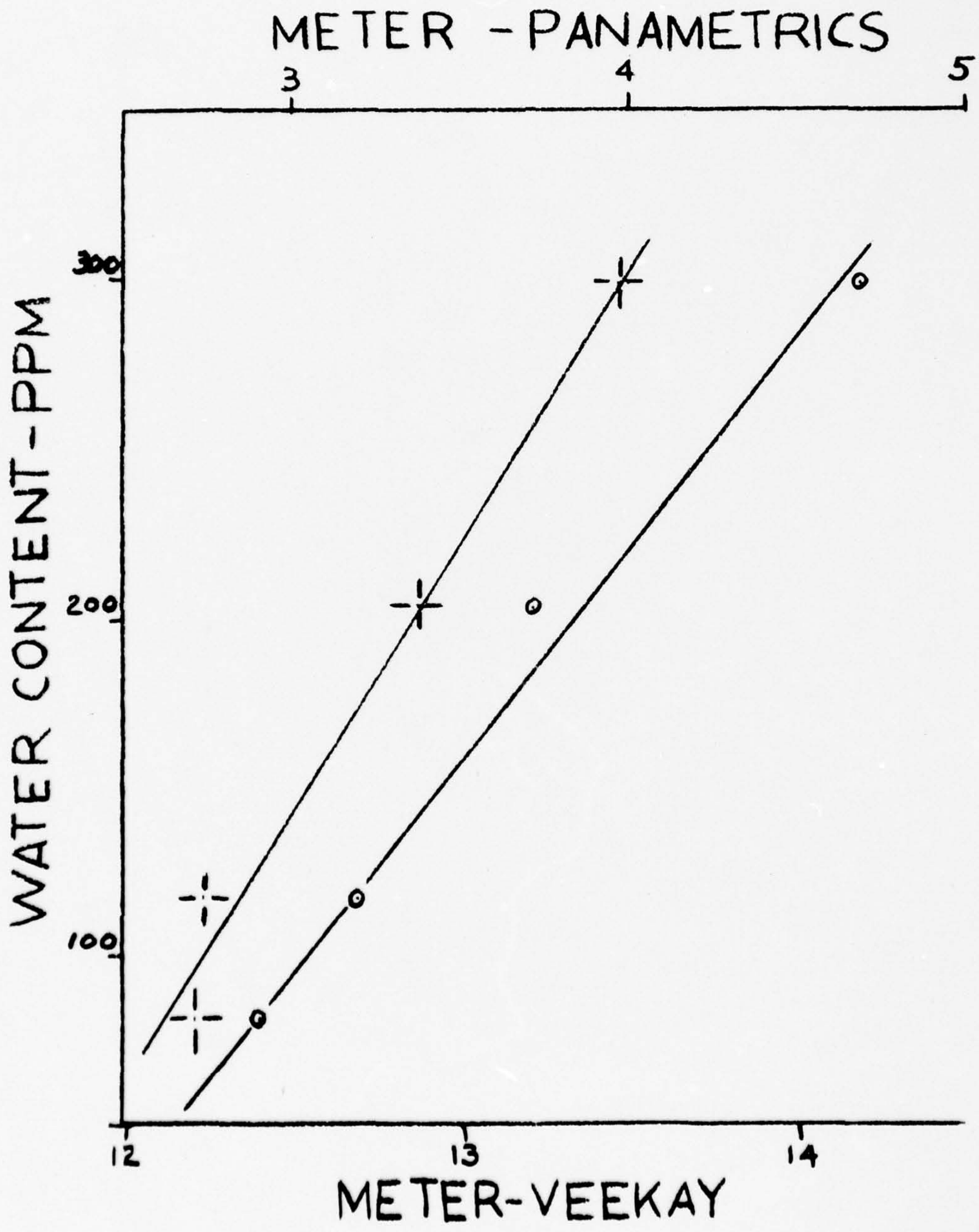


FIGURE 22 - Comparison of Panametrics and VeeKay Hygrometer readings on July 9,1975.

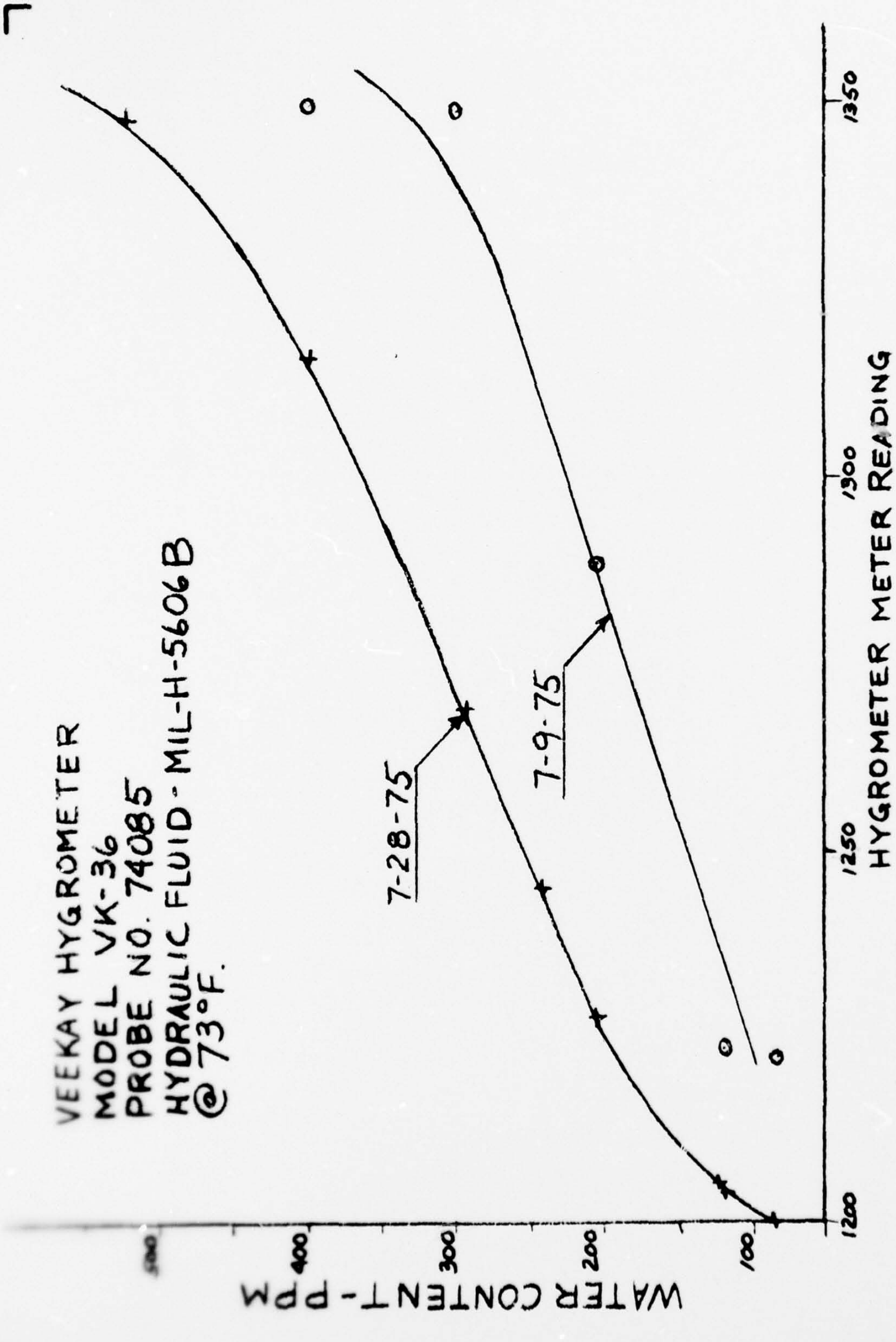


FIGURE 23 - LABORATORY TEST, VEEKAY HYGROMETER.

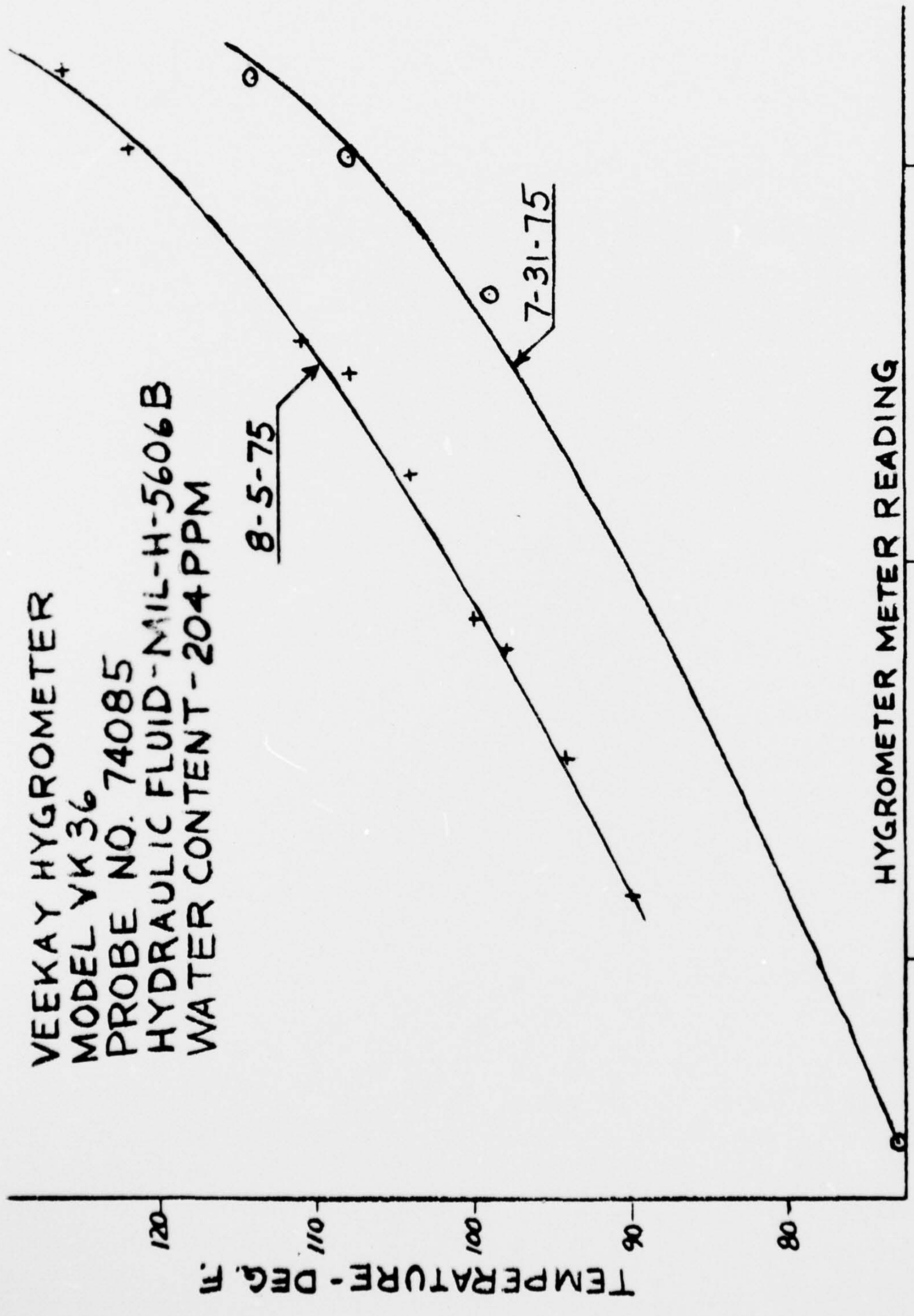


FIGURE 24- EFFECT OF TEMPERATURE ON HYGROMETER READING.

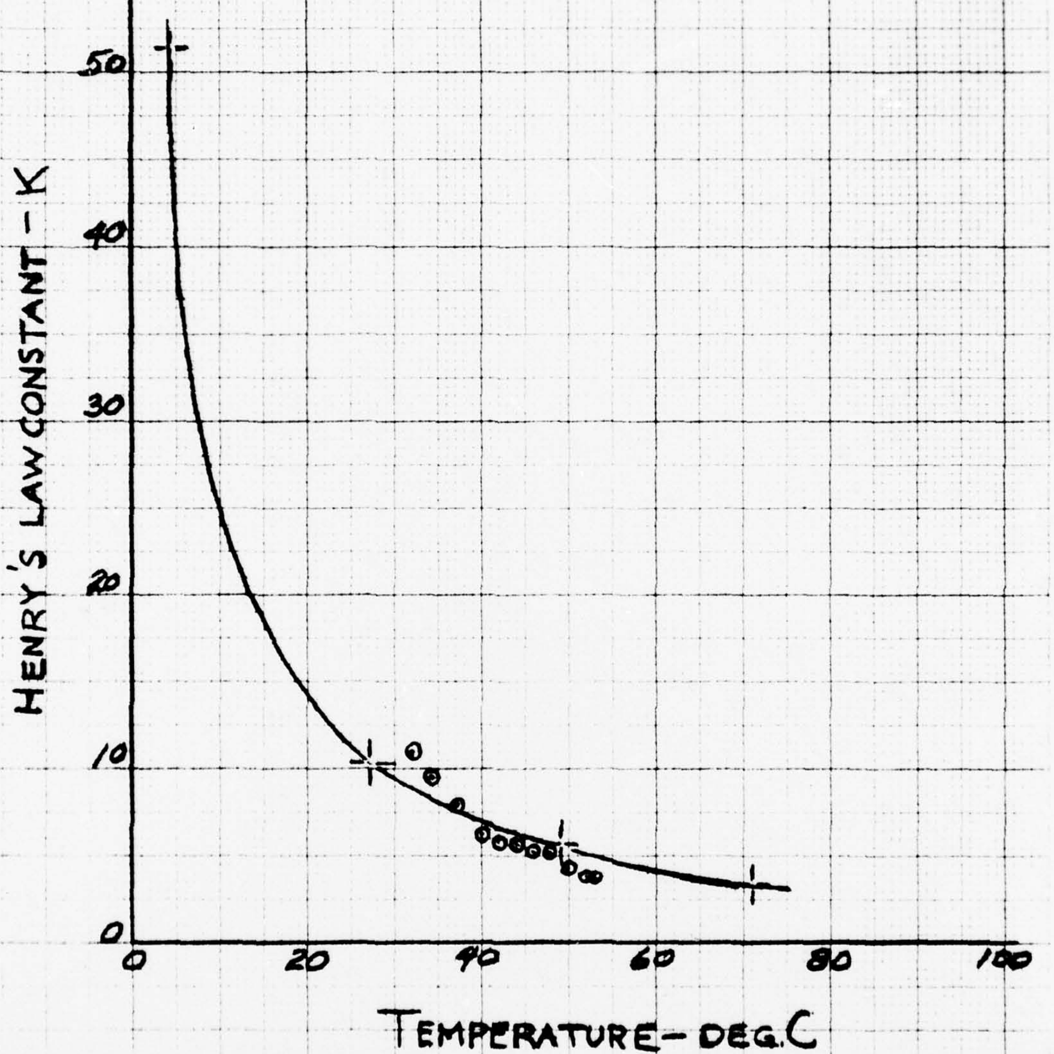


FIGURE 25-
VARIATION OF HENRY'S LAW CONSTANT WITH TEMPERATURE OF MIL-H-5606B HYDRAULIC FLUID.

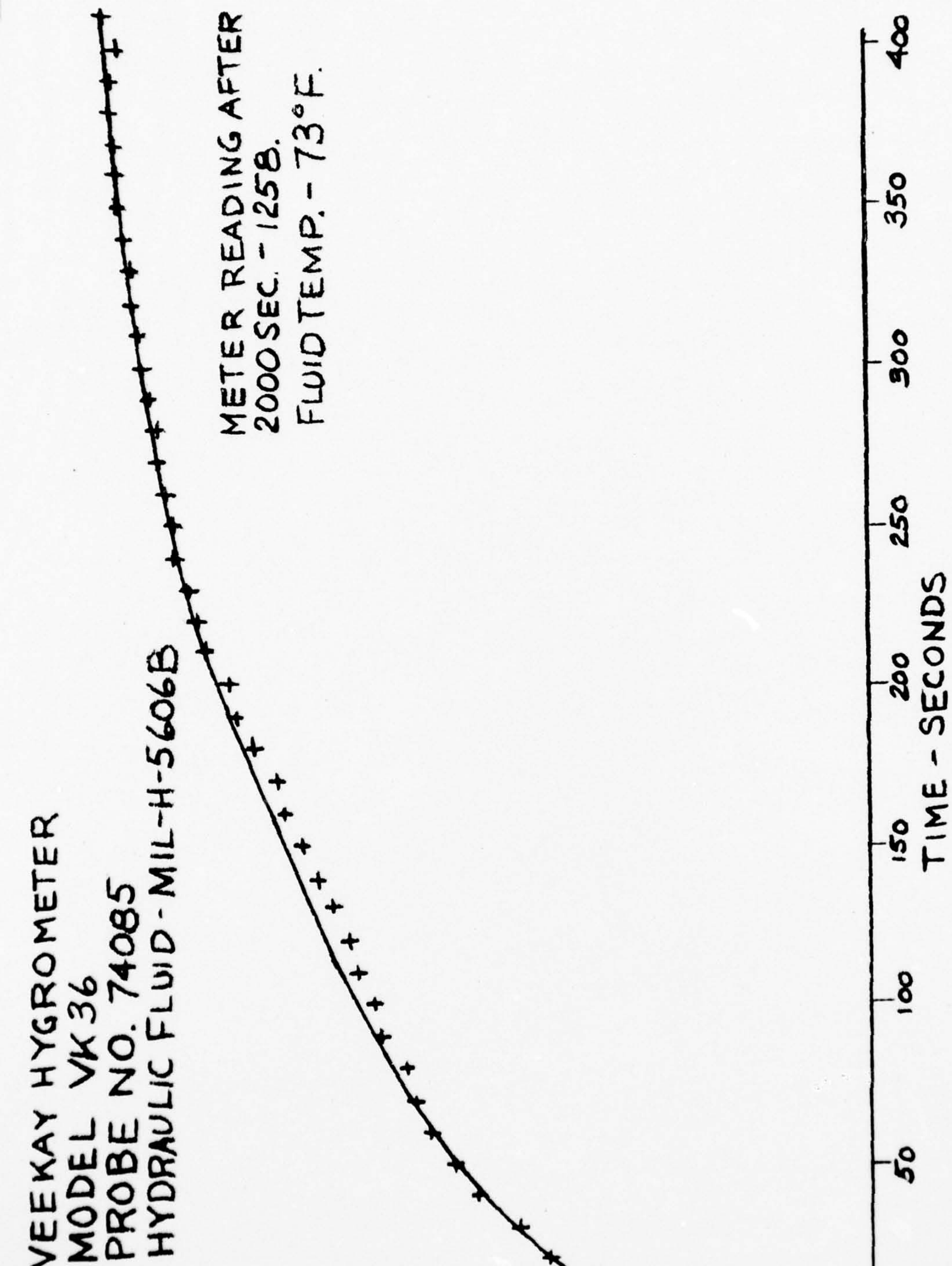


FIGURE 26-VARIATION OF HYGROMETER READING WITH TIME.

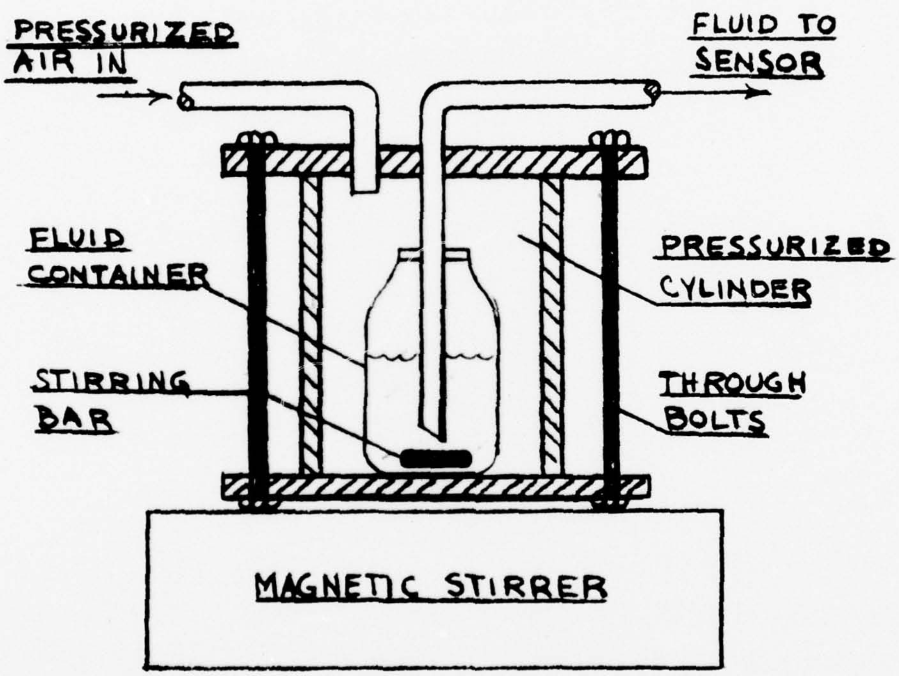


FIGURE 27 - HIAC CALIBRATION SET-UP.

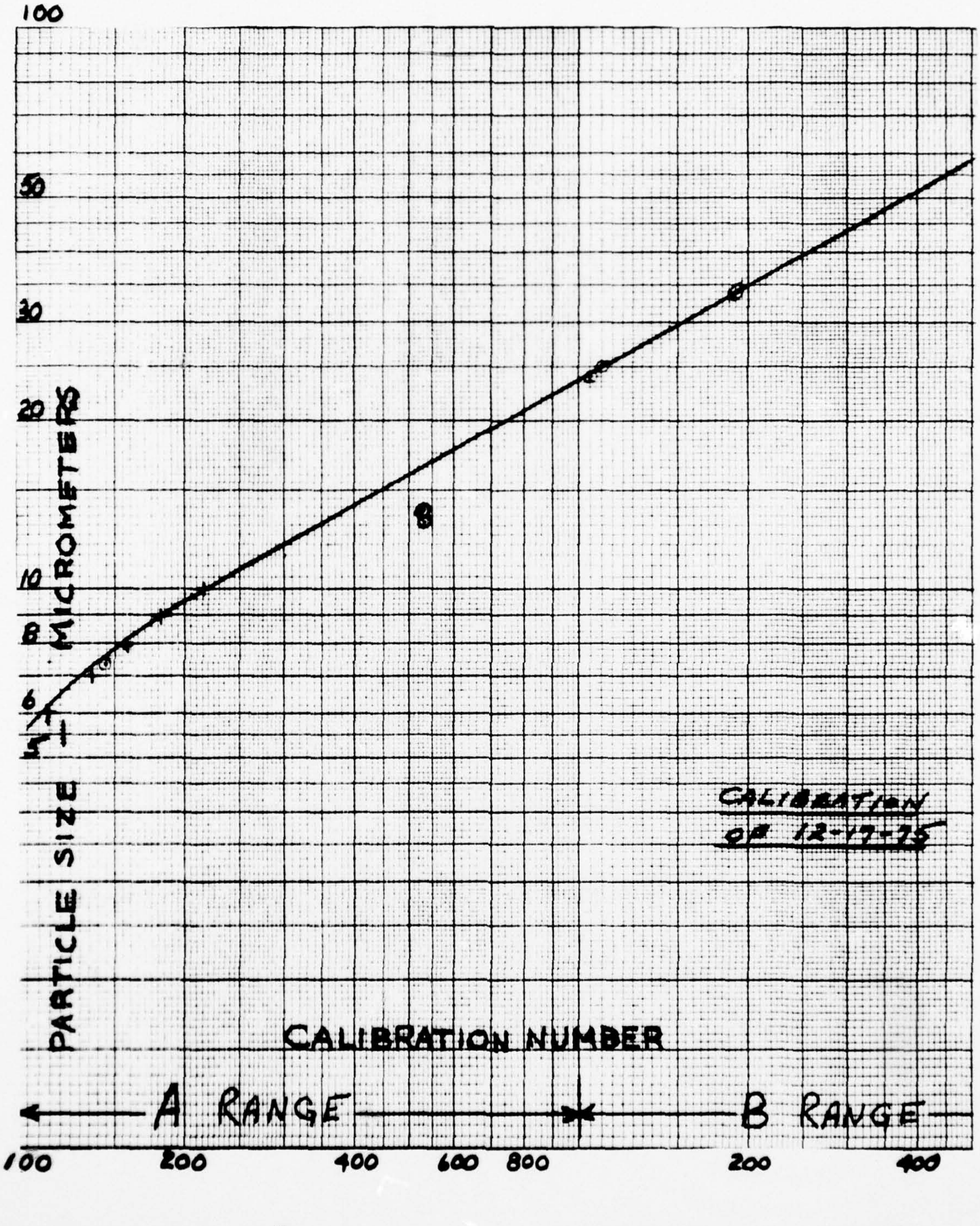


FIGURE 28 - HIAC CALIBRATION CURVE OF 12-17-75.

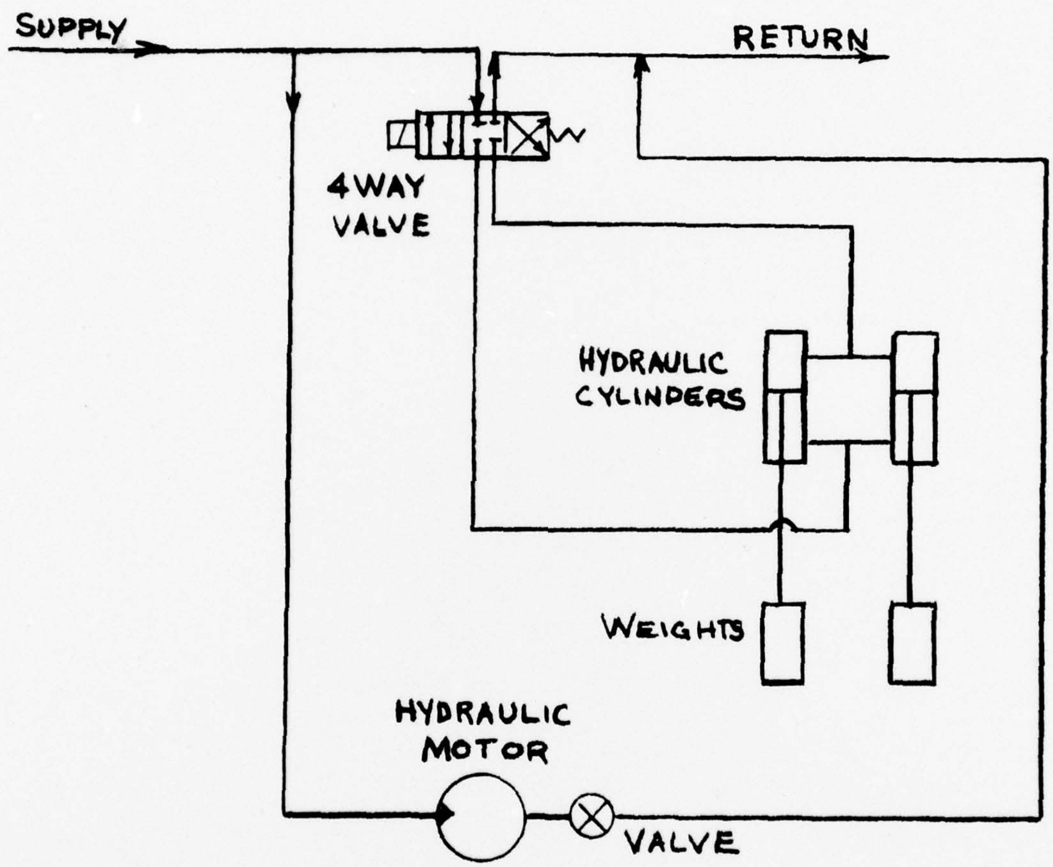


Figure 29 - Aircraft Hydraulic System Simulator Schematic.

APPENDIX A

SPECIFICATION

HYDRAULIC CONTAMINATION MONITOR

MODEL

1. SCOPE - This specification covers the requirements for a portable hydraulic contamination monitor for both flight line and shipboard use to measure particulate contamination in the return flow from an aircraft to a portable hydraulic stand.

2. APPLICABLE DOCUMENTS

2.1 The following specifications, standards, drawings, and publications of the issue in effect on the date of the invitation for bids, form a part of this specification to the extent specified herein.

Where the requirements of this specification conflict with the tabulation of the applicable documents, this detail specification will govern.

SPECIFICATIONS

Military

MIL-D-1000	Drawings, Engineering and Associated List
MIL-I-3661	Lampholders, Indicator Lights, Indicator Light Housings, and Indicator Light Lenses, General Specifications for
MIL-C-5015	Connector, Electric, AN Type
MIL-W-5086	Wire, Electric, 600 Volt, Copper
MIL-W-5088	Wire, Aircraft, Installation of
MIL-T-5422	Testing, Environmental, Aircraft Electronic Equipment
MIL-H-5606	Hydraulic Fluid, Petroleum Base, Aircraft, Missile, and Ordnance
MIL-H-6088	Hydraulic Fluid, Petroleum Base, for Preservation and Testing
MIL-M-8609	Motors, DC, 28 Volt System, Aircraft, General Specification for
MIL-I-45208	Quality Program Requirements
MIL-P-15024/1	Plate, Identification Set or Group
MIL-N-18307	Nomenclature and Identification for Electronic, Aeronautical, and Aeronautical Support Equipment Including Ground Support Equipment
MIL-S-19500	Semiconductor Device, General Specification for
MIL-T-21200	Test Equipment for Use with Electronic and Electrical Equipment, General Specification for
MIL-H-25597	Hose Assembly Tetrafluoroethylene, High Temperature, Medium Pressure
MIL-M-38510	Microcircuits, General Specification for

MIL-C-45662	Calibration System Requirements
MIL-H-83282	Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Aircraft

STANDARDS

Federal

FED-STD-595	Colors for Ready Mixed Paints
FED-STD-791	Lubricants, Liquid Fuels, and Related Products; Methods of Testing

Military

MIL-STD-130	Identification Marking of U.S. Military Property
MIL-STD-143	Standards and Specifications, Order of Precedence for the selection of
MIL-STD-454	Standard General Requirements for Electronic Equipment
MIL-STD-461	Electromagnetic Interference Characteristics, Requirements for Equipment
MIL-STD-462	Electromagnetic Interference Characteristics, Measurements of
MIL-STD-470	Maintainability Program Requirements
MIL-STD-471	Maintainability Demonstration
MIL-STD-701	Preferred and Guidance List of Semiconductor Devices
MIL-STD-756	Reliability Prediction
MIL-STD-781	Reliability Test Exponential Distribution
MIL-STD-785	Reliability Program for Systems and Equipment Development and Production
MIL-STD-810	Environmental Test Methods
MIL-STD-808	Finishes, Protective, and Codes, for Finishing Schemes for Ground and Ground Support Equipment
MIL-STD-831	Test Reports, Preparation of
MIL-STD-847	Format Requirements for Scientific and Technical Reports prepared by or for the Department of Defense
MIL-STD-1562	List of Standard Microcircuits
MS-33656	Fitting End, Standard Dimensions for Flared Tube Connection and Gasket Seal
MS-33649	Bosses, Standard Dimension for Gasket Seal Straight Thread

Naval Air Systems Command

NAVAIR-01-1A-17	Aviation Hydraulics Manual
NAVAIR-16-1-525	Preferred Standard Test Equipment (Avionics)

Drawings

Naval Air Engineering Center

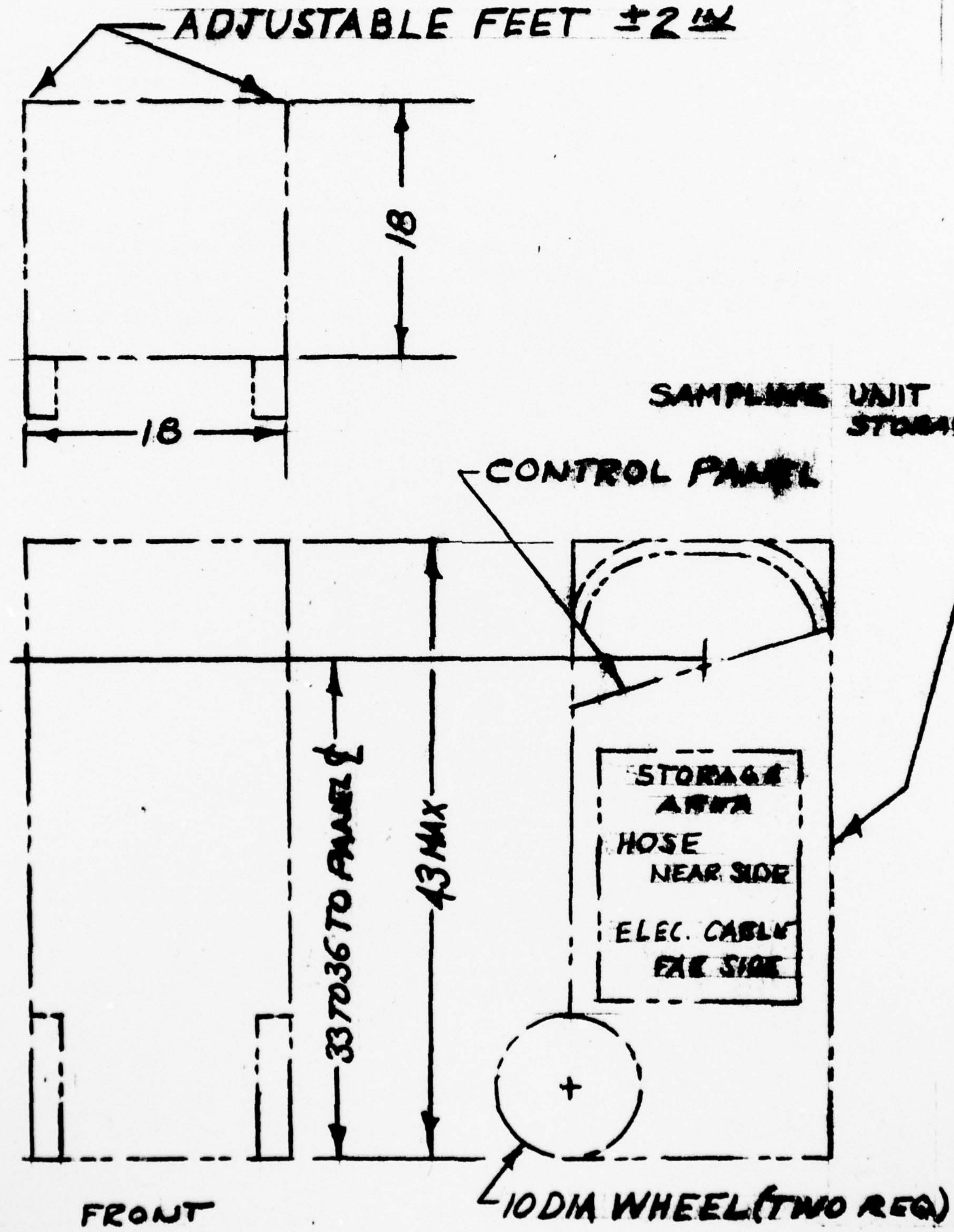
NAEC GSED	DWG. 5SE00363-3	Modification Plate

Other Publications

MIL-HDBK-472	Maintainability Prediction
MIL-HDBK-217B	Reliability Prediction of Electronic Equipment
ANSl B93.28-1973	Method for Calibration of Liquid Automatic Particle Counters Using "AC" Fine Test Dust

When requesting applicable documents, refer to both title and number. Copies of documents may be obtained from the Commanding Officer, Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, Pennsylvania, 19120.

Copies of the ANSI publication may be obtained from the American National Standards Institute, 1430 Broadway, New York, New York, 10018.



HYDRAULIC CONTAMINATION MONITOR
FIGURE 1

3. REQUIREMENTS

3.1 Inspection - The hydraulic contamination monitor furnished shall be a product which has been tested in accordance with the quality assurance provisions specified herein.

3.1.1 Safety - The safety engineering criteria of MIL-STD-454 Requirement 1, shall be incorporated into the design of this contamination monitor.

3.2 Design and Construction - The design and construction of the contamination monitor shall be in accordance with MIL-T-21200, class 2 and the detail requirements specified herein. All requirements of MIL-T-21200 for class 2 equipment apply unless specifically deleted, modified, or waived herein or in the contract. Additional detailed or supplemental requirements may be specified herein for a general requirement listed in MIL-T-21200. This does not constitute a waiver of the general requirement. If a conflict exists between this specification and any document specified herein, this specification takes precedence.

3.2.1 Selection of parts, materials, and processes - The selection of parts, materials, and processes shall be in accordance with MIL-T-21200. It is intended that whenever industrial or commercial specifications are applicable, they may be used when they are technically suited and provide for economy. The order of precedence for the selection of these specifications or standards shall be governed by MIL-STD-143.

3.2.1.1 Compatibility - The contamination monitor shall be constructed of materials that will not adversely affect or be affected by hydraulic fluid conforming to MIL-H-5606, MIL-H-6083, or MIL-H-83282, even when these fluids are contaminated by halogens and chlorides up to a maximum of 1000 ppm. These contaminants are produced by freon and trichlorethylene.

3.2.1.2 Fungi nutrients - Materials which are not nutrients for fungi shall be used wherever possible. Where fungus-nutrient materials must be used, they shall be treated with a fungicidal agent acceptable to the procuring activity.

3.2.1.3 Hydraulic fittings - All fittings and threaded bosses in all components shall be as specified in Standards MS-33649 and MS-33656. The use of taper pipe threads shall be held to a minimum. Where quick disconnects are used, they should seal at each end and be provided with dust covers. - MS

3.2.1.4 Wiring - All wiring shall conform generally to aircraft wiring practice using wire which conforms to specification MIL-W-5086, and using AN/MS terminals, and connectors in accordance with MIL-C-5015 where applicable. Quick disconnect type splices shall not be used. Mechanical strength as well as electrical characteristics shall be considered in the selection of wire gauges used. Installation and wire coding shall conform to MIL-W-5088. All electrical connections shall be marked in accordance

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with MIL-STD-130. Insofar as practicable, all connectors on the front panel shall be mounted along the lower edge of the panel and in no case shall their location be such that the connecting cables will interfere with the operating controls.

3.2.1.5 Microelectronic items - Choice and application of microelectronic items shall be in accordance with MIL-STD-1652 and MIL-M-38510.

3.2.1.6 Semi-conductor devices - Choice and application of semiconductor devices shall conform to MIL-STD-701 and MIL-S-19500.

3.2.1.7 Electron tubes - Semiconductor devices are preferred to electron tubes, wherever practicable. If electron tubes are used, they shall be in accordance with MIL-STD-454, Requirement 29.

3.2.2 Functional units - The hydraulic contamination monitor shall consist of three units: a sensing unit for detecting particulate contamination, an analytical unit for measuring size and quantity of particulate contamination, and a sampling unit. The sensing and analytical units shall be combined in one enclosure as specified in paragraph 3.2.6.

3.2.2.1 Sensing unit - The sensing unit consists of a restricted orifice and some means of detecting particulate contamination. Power for the sensing unit shall be provided from the analytical unit. The contamination monitor shall be provided with a flow measuring device to insure that flow requirements are met.

3.2.2.1.1 Flow requirements - The flow rate to the sensing unit shall be such that it shall be reading fluid passing through the sampling unit within 30 seconds after opening the valve connecting the sensing unit with the sampling unit. If this requirement cannot be met, then a bypass of the sensing unit shall be provided to expedite flow to the sensing unit. The sensing unit shall be provided with a pump to satisfy the liquid flow requirements.

3.2.2.1.2 Operating pressure - The contamination monitor shall meet the test requirements specified in paragraph 4.5.6.1 of this specification.

3.2.2.1.3 Screen - A protective screen shall be provided upstream of the sensor of such mesh size to prevent large particles from clogging the sensor orifice. The screen shall be removable for replacement or cleaning in such a way that the task of removal and replacement can be completed in five minutes or less.

3.2.2.2 Analytical unit - The analytical unit shall be designed to receive the input power for the contamination monitor. It shall analyse the output of the sensing unit to determine if contamination limits are exceeded, and provide a suitable display to show the condition of the fluid being monitored.

3.2.2.2.1 Power input - The contamination monitor shall be operable from both 110 volts AC, 60 Hz, and a DC power source which may vary from 22 to 28 volts. The performance of the contamination monitor shall not be degraded by the aforementioned voltage variations. The analytical unit shall be provided with a method of selecting either AC or DC power and shall provide electrical power for the rest of the contamination monitor.

3.2.2.2.2 Contamination measurement gauges - Contamination measurement gauges shall be dial-indicating instruments and meet the accuracy requirements of MIL-STD-454, Requirement 51. Instrument dials shall have a white background with a nameplate for insertion of service information. The contamination measurement gauges shall show the acceptable operating region by a green bar, and the unacceptable operating region by a red bar. The dividing line between the two regions shall be at the mid-point of the scale as specified in paragraph 4.5.5.1.8. The usable gauge length shall have a minimum length of 3 inches and a minimum needle movement of 90 degrees, and be subdivided into two equal parts. All indicating instruments, dials, and sight tubes shall be flush panel mounted, and illuminated for night use.

3.2.2.2.3 Warning light - A red light mounted on the operating panel shall be provided to indicate when the instrument saturation limit has been reached.

3.2.2.3 Sampling unit - The sampling unit shall consist of a section of hydraulic line to be inserted in the return flow line to the portable hydraulic test stand. Sample fluid will be drawn from return line flow of zero to 30 GPM. It shall have quick disconnect fittings at either end. These shall be mounted at each end AEROQUIP (Code Ident 00624) Part Numbers 145-S5-20D and 014519-54-20D equipped with Dust Caps AEROQUIP Part Numbers 145-S9-20D and 145-S7-20D. The direction of flow in the sampling unit shall be from quick disconnect P/N 014519-S4-20D to QD P/N 145-S5-20D and shall be marked and labeled. There shall be provision on the sampling unit for two sample ports; one, a supply line to the contamination monitor and the second, a return. The two connections shall be of hose assemblies per MIL-H-25597 class 1 and shall be from 6 to 10 feet in length.

3.2.2.3.1 Sampling pump The sampling pump shall be electrically driven and operated from power input as specified in paragraph 3.2.2.2.1. Power shall be provided from the analytical unit. The motor shall be drip-proof and shall be rated for continuous duty service at the specified horsepower. The motor shall conform to MIL-M-8609. It should be of such design that it will not generate particulate contamination that affects significantly the cleanliness determination of the monitor. The location of the sampling pump shall be determined by the detail design parameters.

3.2.3 Circuit Protection - The contamination monitor shall be designed to operate without damage, or blowing fuses during the conditions of the source power listed in paragraph 3.2.2.2.1. Fuses shall be provided as necessary to preclude damage to assemblies or components due to a failure of any other assembly or component.

3.2.4 Monitoring - The contamination monitor shall incorporate test points and indicators to show operational status. Operational status shall include input power, circuit functioning, and a self-calibration feature to insure accurate measurement of particulate contamination. Any malfunction of the monitoring system shall not impair the operation of the contamination monitor.

3.2.4.1 Test points - Internal test points shall be provided in accordance with Class C and D requirements of MIL-STD-415.

3.2.4.2 Indicators - The indicators used for the test panels may consist of status lights, multi-legend indicators, or dial indicators. Status lights shall conform to MIL-I-3661 and shall have push to test provision.

3.2.4.3 Grounding - The contamination monitor shall be grounded in accordance with MIL-STD-454, Requirement 1.

3.2.5 Accessibility - The contamination monitor shall have accessibility of components in accordance with MIL-STD-454, Requirement 36.

3.2.6 Enclosure - The sensing and analytical units of the contamination monitor shall be contained in a combination case as defined in Paragraph 3.2.3.3 of MIL-T-21200.

3.2.6.1 Finish - The contamination monitor and its case shall be finished in accordance with the requirements of MIL-STD-808. The color of the exterior finish shall be glossy yellow, color 13538 of FED-STD-595.

3.2.7 Stand - The contamination monitor shall be mounted on a wheeled stand with a configuration and size as shown in Figure 1. Exception to this configuration can be made only with the approval of the procuring activity.

3.2.8 Electromagnetic Interference Characteristics - The contamination monitor shall be designed to conform to the electromagnetic interference requirements in accordance with MIL-STD-461 class IIB. In addition to the requirements of class IIB, the contamination monitor shall be designed to meet the susceptability requirement of RS-03 in accordance with MIL-STD-461.

3.2.9 Interchangeability - All parts having the same part number shall be directly and completely interchangeable with each other, with respect to installation and performance. Matched parts or selective fits shall be used only where absolutely required, and only after approval of the procuring activity. Changes in part numbers shall be governed by the drawing requirements of MIL-D-1000.

3.2.10 Endurance requirements - The contamination monitor shall meet the test requirements specified in paragraph 4.5.6.2 of this specification.

3.3 Performance characteristics - The contamination monitor shall measure the quantity of particulates of 5 to 150 micrometers in size over the gravimetric range of 0.1 to 5.0 milligrams per liter. The monitor shall be designed and constructed to perform the contamination measurements, provide the sensitivity, and be capable of calibration as described in the test in paragraph 4.5.5 of this document.

3.3.1 Environmental - The contamination monitor shall meet the following operating and non-operating environmental requirements and shall be tested in accordance with environmental test methods of MIL-STD-810C in the order listed below:

3.3.1.1 Low temperature test - Method 502.1, Procedure I. The lowest required operating temperature is -20°C.

3.3.1.2 High temperature test - Method 501.1, Procedure II. The highest required operating temperature is 49°C.

3.3.1.3 Shock - Method 516.2, Procedure II. The height of the drop for Procedure II shall be 15 inches and eight drops on each corner.

3.3.1.4 Vibration - Method 514.2, Procedure X, equipment category g. The contamination monitor shall be tested in accordance with curve AW of Figure 514.2-7 for time required in table 514.2-VII transport mode, rail, air, sea, and truck only.

3.3.1.5 Humidity - Method 507.1, Procedure II/

3.3.1.6 Dust - Method 510.1, Procedure I. Test times for steps 1 and 3 shall be reduced to three hours; for step 2 to eight hours.

3.3.1.7 Rain - Method 506.1, Procedure I, except that the rainfall rate of five inches per hour will not be required. Total test time shall not be less than two hours.

3.3.2 Orientation - The contamination monitor shall be operated and demonstrate full performance when tilted in any direction from the normal operating position at an angle of 30 degrees.

3.4 Reliability - The contractor shall conduct a reliability program in accordance with MIL-STD-785. The specified mean time between failure (MTBF) for the contamination monitor is 1000 hours. Circuits and components shall be chosen so that the stress limits, specified in the manufacturer and/or vendor's technical data description, are of sufficient margin to ensure the proper operation and reliability required to support the MTBF and life expectancy of the subject circuits and components. The equipment furnished under this document shall successfully pass a reliability demonstration as specified in paragraph 4.5.10.

3.4.1 Reliability Program - The contractor shall conduct an approved reliability program as set forth in 3.4 of this document. The format of documentation shall be in accordance with MIL-STD-847.

3.4.1.1 Program plan - A Reliability Program Plan, in accordance with 4.4 of MIL-STD-785A shall be submitted to the procuring activity as part of the design proposal. The content of the Reliability Program Plan shall be in accordance with Section 5 of MIL-STD-785A. The contractor shall include in the Reliability Program Plan methods to insure that results of reliability analysis will produce confirmation of, or change to, the design. The contractor shall include in the Reliability Program Plan a schedule of the reliability tasks indicating significant program milestones. Provisions shall be included which will assure timely completion and application of interim and final results of each task.

3.4.1.2 Program reviews - Scheduled Formal Program Reviews per 5.1.4 of MIL-STD-785A, shall be conducted commencing 60 days after contract award, and whenever the situation indicates the necessity for additional reviews. Procuring activity personnel shall be notified of such additional reviews at least ten working days prior to the review. An agenda shall be proposed to the procuring activity at the time of notification. The Program Review shall include, but not be limited to, the status of each reliability task, an assessment of the reliability progress, results of the reliability design reviews, results of testing, and resultant planned and implemented design changes.

3.4.1.2.1 Status reports - The contractor shall prepare monthly reliability program status reports as described in paragraph 5.6 of MIL-STD-785A.

3.4.1.3 Design reviews - Formal Design Reviews in accordance with 5.2.7 of MIL-STD-785A shall be conducted in conjunction with the regularly scheduled Program Reviews and whenever the situation indicates the necessity for additional reviews. The design review shall be conducted by contractor personnel independent of the equipment design team. Procuring activity personnel shall be in-

vited to participate. Procuring activity personnel shall be notified of any planned or additional reviews at least ten working days prior to the review. A detailed report of all Formal Design Reviews shall be prepared and submitted in accordance with 5.2.7 of MIL-STD-785A. As a minimum, one review shall be held before start of the first article test report.

3.4.1.4 Subcontractor and supplier reliability programs - The contractor shall be responsible for all subcontractor and vendor reliability programs. Applicable reliability requirements shall be established for inclusion within subcontractor and supplier procurement documentation.

3.4.1.5 Program interface - The contractor shall be responsible for interfacing efforts in accordance with 5.1.2.2 of MIL-STD-785A.

3.4.2 Reliability analysis - The contractor shall perform a reliability analysis commencing with contract initiation and shall include the requirements of 5.2.2 of MIL-STD-785A and subparagraphs thereto. The analysis shall include a reliability apportionment, a mathematical model, and a prediction. The reliability prediction shall be in accordance with MIL-STD-756A, Design Prediction Procedure. MIL-HDBK-217B shall be utilized as the source of reliability data wherever applicable. Work sheets shall be utilized, in the computation of part failure rates, which list all factors necessary to substantiate the results. The prediction shall be updated whenever the design is changed or test data is available.

3.4.2.1 Failure modes and effects analysis (FMEA) - A FMEA shall be conducted in accordance with MIL-STD-1629 and will serve as a tool in further developing the mathematical models, in reapportioning and updating predicted reliability, and determining weak areas. The technique to be used in performing the FMEA shall be described in the Reliability Program Plan.

3.4.2.2 Failure reporting, analysis, and corrective action - Procedures for failure reporting, analysis, and corrective action shall be included in the Reliability Program Plan as called for by 5.4.1 of MIL-STD-785A. Failure summaries shall be included in the Reliability Status Reports and be continuously updated.

3.4.2.3 Failure reports - Any and all failures (both relevant and irrelevant) which occur during equipment tests shall be recorded and reported in accordance with the applicable reliability test specification and the failure reporting, analysis, and corrective action requirements of the approved Reliability Program Plan.

3.4.2.4 Failure analysis - An analysis of the cause of each failure shall be made in accordance with the applicable reliability test specification and the failure reporting, analysis, and corrective action requirements of the approved Reliability Program Plan.

3.5 Maintainability

3.5.1 General requirement - The contamination monitor shall have a Mean Time to Repair (MTTR) at the intermediate level of 1.0 hours or less. Maximum Mean Time to Repair, 2.0 hours. Time to Repair shall be defined as time necessary to return the unit to operating status, exclusive of time spent in transit to and from the service area. The contractor shall take steps to insure ready access to all components to be adjusted in order to maximize utility of the equipment. Maintenance will require only equipment found in NAVAIR 16-1-525.

3.5.1.1 Maintainability program - The contractor shall develop and implement a maintainability program in accordance with MIL-STD 470. The maintainability program shall be responsive to the mission requirements together with the specific maintainability requirements set forth in 3.5 of this specification.

3.5.1.1.1 Program plan - A Maintainability Program Plan shall be submitted to the procuring activity as part of the design proposal. This program plan shall be in accordance with 5.1 of MIL-STD-470 and have paragraph headings similar to Section 5 of MIL-STD-470. The contractor shall include in the Maintainability Program Plan, methods to insure that results of the analysis will produce confirmation of, or change to, the design.

3.5.1.1.2 Program reviews - Scheduled Formal Program Reviews shall be conducted commencing 60 days after contract award and whenever the situation indicates the necessity for additional reviews at least ten working days prior to the review. An agenda shall be proposed to the procuring activity at the time of notification. The Program Review shall be combined with the Reliability Program Review required by paragraph 3.4.1.2.

3.5.1.1.3 Program interface - The contractor shall be responsible for interfacing efforts in accordance with 5.1h of MIL-STD-470.

3.5.2 Maintainability predictions - Maintainability predictions shall be in accordance with Procedure II, Part A of MIL-HDBK-472. The contractor shall submit the technique of Maintainability Prediction to the procuring activity for approval along with the Maintainability Program Plan. The prediction technique shall identify the assumed maintainability distribution. Additional predictions shall be made whenever a significant design change occurs that would appreciably increase repair time for any subassembly. These predictions shall represent the current state of the design at the time when they are made.

3.5.3 Design reviews - Formal Design Reviews per 5.9 of MIL-STD-470 shall be conducted by contractor personnel. Procuring activity personnel shall be notified of any planned or additional reviews at least ten working days prior to the review. The design reviews shall be combined with the Reliability Program Reviews required by paragraph 3.4.1.2 and equipment design review.

3.6 Operating and maintenance instruction - A brief set of operating instructions including schematic diagram shall be attached where readily accessible to the operator. The operating instruction plate, or plates, shall be made of aluminum in accordance with MIL-P-15024 Type H, Style III, and shall be mechanically attached to the unit.

3.7 Identification and nomenclature - The contamination monitor shall have an identification plate conforming to MIL-P-15024/1, Type H. Nomenclature assignment shall be in accordance with MIL-N-18307. The plate shall contain the NAEC part number, the contract number, and the manufacturer's part and serial numbers.

3.8 Workmanship - Workmanship shall be in accordance with MIL-STD-454, requirement 9.

3.9 Modification plate - A modification plate in accordance with NAEC GSED Drawing 5SE00363-3 shall be installed on the front of the unit. This plate shall be readily accessible and used to record incorporation of changes into the individual contamination monitor.

3.10 Utilization - The contamination monitor shall be assumed to have a duty utilization time of 0.5 to 6 hours.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection - Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract or order, the supplier may use his own or any other facilities suitable for the performance of the inspection requirements specified herein, unless disapproved by the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure suppliers and services perform to prescribed requirements specified in Section 3.

4.1.1 Contractor's quality assurance system - The contractor shall have in effect at award and shall provide and maintain an effective inspection and quality control system in accordance with MIL-I-45208A during the life of the contract. All quality assurance operations performed by the contractor will be subject to Government verification at any time.

4.1.2 Test plan - A proposed test plan shall be prepared by the contractor for approval and shall be submitted 90 days before the start of testing. The test plan shall detail all test procedure, calibration methods, identify instrument and equipment, and describe test set ups which are required to meet the test requirements specified herein. The test plan shall be organized into separate parts to match the group of tests listed in paragraph 4.3, including reliability and maintainability demonstration.

4.1.2.1 Test equipment - Test equipment used in conjunction with the testing specified herein shall be of the laboratory precision type. Permanent records shall be made of all tests with light beam recording type instruments having a minimum frequency response of not less than 1000 cps. Pen type recorders may be used for specific tests as authorized by the procuring activity.

4.1.2.2 Test equipment calibration - Test equipment shall be calibrated in accordance with MIL-C-45662.

4.2 Test conditions - Unless otherwise specified herein, all tests shall be conducted under standard ambient conditions as defined in MIL-STD-810C paragraph 3.1a, ($77^\circ \pm 5^\circ$F, 29.92 $\pm$ 0.3 inches Hg and 40 to 50 percent relative humidity).

4.3 Quality conformance testing - Unless otherwise specified therein, the first unit produced shall be subject to and must pass all four classifications of tests listed below. Subsequent units will be required to pass Group A test and any other tests specified in the procurement contract.

Acceptance test	Group A
Qualification test	Group B
Reliability test	Group C
Maintainability test	Group D

4.3.1 Test requirements - Table I shows a tabulation of the tests required for each classification.

TABLE I

Tests	Requirement paragraph	Test paragraph	Group A	Group B	Group C	Group D
Examination of product	3.	4.5.1	X	X^1	X^1	X^1
Flow test	3.2.2.1.1	4.5.3	X			
Operating pressure	3.2.2.1.2	4.5.6.1	X			
Power input	3.2.2.2.1	4.5.4.1	X			
Warning light	3.2.2.2.3	4.5.6.3	X			
Grounding	3.2.4.3	4.5.4.2	X			
Endurance	3.2.10	4.5.6.2	X			
Size	3.2.7	4.5.2	X			
Contamination measurement	3.3	4.5.5	X	X^1	X^1	X^1
Low temperature	3.3.1.1	4.5.7.1		X		
High temperature	3.3.1.2	4.5.7.2		X		
Shock	3.3.1.3	4.5.7.3		X		
Vibration	3.3.1.4	4.5.7.4		X		
Humidity	3.3.1.5	4.5.7.5		X		
Dust	3.3.1.6	4.5.7.6		X		
Rain	3.3.1.7	4.5.7.7		X		
EMI	3.2.8	4.5.8		X		
Inclined operation	3.3.2	4.5.9		X		
Reliability	3.4	4.5.10			X	
Maintainability	3.5	4.5.11				X

Note 1 - Shall be performed both before and after test as required in test procedures.

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4.3.1.1 Test Report - After the satisfactory completion of tests, the contractor shall prepare a test report for each unit in accordance with MIL-STD-831 and furnish three copies to the procuring activity for review and acceptance per contract terms. The report shall contain complete detailed records of the tests including data sheets, performance curves, chronological test records, photographs, sample calculations, description of test instrument, set-up diagrams and conclusions and recommendations.

4.4 Failure - A failure is classified as any condition that will preclude acceptance of the equipment for compliance with test/inspection requirements specified herein. Failure actions of paragraph 5.5 in MIL-STD-781 shall apply.

4.4.1 Failure Definitions - All failures shall be reported and defined in terms of the failure types and categories listed below:

Failure Types

Type I: Must stop operations to fix or repair. The equipment is unable to go through one more operating cycle or a condition exists where the safety of the equipment, operator or plane would be in jeopardy if operations were to continue. Failures in this category result in abort of remaining mission.

Type II: Operations may continue, but monitoring of the failed, or malfunctioning component (or subsystem) is required.

Type III: Failure or malfunction is not serious in terms of continued operations, and repair or replacement can be safety deferred.

Type IV: Equipment has experienced a catastrophic or major failure. System required extensive repairs and are of type not normally accomplished by local maintenance personnel. These repairs are generally characterized by high repair manhours and long downtime periods.

Failure Categories

Relevant Failure - A relevant failure is the inability of the item to perform any one of its intended and specified functions within the specified limits. Type I and Type IV failures defined herein are considered relevant failures. All failures are considered relevant until classified as non-relevant by one of the following provisions and subparagraph (e) below:

Non Relevant Failures - Non Relevant failures are those due to the following causes:

(a) A secondary or dependent failure that is caused by the failure of associated items. For every secondary failure classified as not relevant, a primary or independent failure shall be identified. Only one secondary non relevant failure of the same part (same drawing number or other unique identifier) shall be allowed during the test. The second and later failures of the same part shall be counted as relevant and corrective action shall be taken to reduce the failure rate of such parts to acceptable levels.

(b) A test operator or test facility indiced failure may be classified as non relevant if it can be substantiated that the equipment was subjected

to operation or stress conditions beyond specified limits.

(c) Changes to the item to correct a deficiency that caused a failure shall not classify such a failure as not relevant until the change has been demonstrated as a fully effective correction to the satisfaction of the procuring activity.

(d) Preventive maintenance, servicing, and adjustments may be counted as non relevant if such actions are specified as normal maintenance in the existing or planned technical manuals to be supplied for use with the equipment.

(e) Complete data shall be taken and retained for the analysis, tests, and other actions taken to fully justify each classification of a failure as non relevant.

(f) Type II and Type III failures defined herein shall be considered non relevant failures except in the event that they degenerate into a Type I or Type IV failure.

4.4.2 Equipment Failure - Should a failure occur during test, the following actions shall be taken:

(a) Determine the cause of failure.

(b) Determine if the failure is an isolated case or design defect.

(c) A component failure analysis and an engineering analysis of the problem shall be provided to the procuring activity.

4.4.3 Rejection and Retest - When a contamination monitor fails to meet specifications, acceptance will be withheld until the requirements of paragraph 4.4.2 have been met. After correction of a failure as specified above, tests to the extent deemed necessary by the procuring activity shall be repeated.

4.4.4 Defects in equipments already accepted - The investigation of a test failure could indicate that defects may exist in units already accepted. If so, the contractor shall fully advise the procuring activity of all defects likely to be found and methods of correcting them.

4.5 Test Procedures

4.5.1 Examination of product - Parts of assemblies and completed units shall be examined as specified in 4.5.1.1 and 4.5.1.2 to determine conformance with this specification.

4.5.1.1 Major parts - Examination shall be conducted to determine:

a. All of the following items conform to applicable specification and that the size, type, and rating are shown on the approved drawing/specification.

1. Resistors and rheostats

2. Instruments, instrument transformers, shunts, and other associated accessories.

3. Capacitors

4. Switches

5. Semiconductor devices

6. Terminal boards

7. All laminated materials, such as glass mica glass (GMG), glass silicon glass (GSG), used for terminal boards; sub-panels, and so forth.

b. All materials used in the construction of wound components comply with the material requirements as shown on the approved drawing/specification.

1. All windings were given varnish impregnation in accordance with the procedures shown on the approved drawing/specification.

2. The resistance of all windings is as shown on the approved drawing. Number of turns shall be as specified on approval drawing/specification.

4.5.1.2 Completed contamination monitor - Examination shall be conducted to determine that:

a. All parts or sub-assemblies are mounted as shown on the approved drawing/specification.

b. All parts which require servicing, repair, replacement, or periodic adjustment during the life of the equipment are readily accessible.

c. All parts and assemblies are marked with identifying symbols, and these symbols agree with those used on the approved drawing/specification.

d. All terminals of all parts and subassemblies and terminal boards are marked with identifying letters and numbers, or both, and this identification agrees with those used on the approved drawing/ specification.

e. Wire used for interconnecting parts or subassemblies are of the type(s) shown on the approved drawing/specification.

f. All wiring is neatly formed into groups and laced with flame-resistant tie or glass cord and supported or clamped in a manner which will prevent chafing of the insulation due to vibration and shock.

g. Cable clamps used are of flame-resistant material.

h. There are no splices in any of the wires.

i. Wire groups from hinged doors and panels are formed and clamped in a manner that sharp bends do not occur with the panel or door in the open or closed position.

j. Sufficient slack in wiring is allowed so that the weight of the harness is not supported by the terminal connections; and, so that at least two replacements can be made if lugs are clipped off at the wire end.

k. Cable entrance provisions and receptacles are as shown on the approved drawing/specification.

l. Sufficient space is provided for these receptacles and sufficient cable support within the enclosure, and connections made at the appropriate terminals.

m. Wherever wires run through holes in metal partitions or chassis, grommets are provided for mechanical protection.

n. Wires are not bent around sharp corners which may injure the insulation.

o. All wires are connected by either bolted or soldered connections.

p. All bolted connections are provided with locking devices.

q. Both ends of all wires are marked with designations as shown on the approved drawing/specification.

r. Hinged doors and panels do not bind when opening.

s. All identification and instruction plates are furnished as shown on the approved drawing/specification.

4.5.2 Size - The contamination monitor shall be measured with dimensions recorded to show conformance with paragraph 3.2.7. The monitor shall be weighed and the weight recorded in test report.

4.5.3 Flow test - The contractor shall submit to the procuring activity a flow analysis to verify that the flow requirements of paragraph 3.2.1.1 are satisfied.

4.5.4 Electrical tests

4.5.4.1 Power input - The contractor shall demonstrate operability of the contamination monitor from either 110 volts AC, 60Hz, or 24 volts DC (+4/-2). The contamination monitor shall be operated at the extreme limits of voltage without degradation of performance.

4.5.4.2 Grounding - The contamination monitor will be examined for compliance with paragraph 3.2.4.3. A checklist shall be prepared and utilized to identify specific area of compliance.

4.5.5 Contamination measurement - There shall be three parts to this test. The first part consists of checking the sensitivity of the contamination monitor over a range of contamination levels. Parts two and three are verification checks of the cleanliness setting of the contamination monitor during clean-up operation of a hydraulic system. All tests shall be conducted at standard ambient conditions as defined in paragraph 4.2 of this specification.

4.5.5.1 Meter sensitivity test - This test shall be conducted using a continuous flow, hydraulic loop. The fluid in the loop shall be MIL-H-5606B hydraulic fluid. AC fine test dust shall be used to simulate the contaminant. The AC fine test dust shall have a particle size distribution which conforms to Table 3 of ANSI specification B93.28-1973. The fluid in the test loop shall be circulating at sufficient velocity that it is in the turbulent flow range at the point where sampling line connects.

4.5.5.1.1 Preparation of contaminant - Determine the total volume of fluid in the test loop. Weigh accurately, within ± 0.1 mg, a sufficient quantity of dried AC fine test dust as determined by calculation shown in Table II. AC fine test dust shall be dried in an oven heated to a temperature of 300°F. for a period of 4 hours. It shall then be stored in a dessicant chamber until used. Deposit this contaminant in a clean sample container and add 1000 ml of accurately measured filtered hydraulic fluid. Place a clean plastic film over the container opening and cap it.

4.5.5.1.2 Disperse and suspend the dust in this concentrated contaminant mixture by violent agitation. This agitation shall consist of five minutes in a paint shaker, thirty seconds in an ultrasonic bath, and another fifteen minutes in the paint shaker.

4.5.5.1.3 Divide the concentrated contaminant mixture into ten portions. The volume of each portion is determined as shown in Table II. These will be added to the test loop in sequence to obtain contamination concentration levels of 0.5,1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, and 5.0 mg/1.

4.5.5.1.4 As each of the portions of the concentrated contaminant mixture is added to the test loop, allow sufficient time for the contamination monitor meter reading to stabilize. Record the meter reading in percent of scale deflection.

4.5.5.1.5 After recording the meter reading, draw a 100 ml sample from the test loop in the vicinity of the sensor unit for subsequent particle count.

4.5.5.1.6 Repeat steps 4.5.5.1.4 and 4.5.5.1.5 until a test loop concentration of 5.0 mg/l is obtained.

4.5.5.1.7 Perform a particle count of the ten samples taken in paragraphs 4.5.5.1.5 and 4.5.5.1,6 for particle size ranges of 5, 10, 25, and 50 micrometers. The particle count may be visual using the method 3009 of Fed-Std-791, or using an automatic particle counter which has been calibrated according to ANSI specification B93.28-1973. The particle counts will be used to verify the contamination levels specified in paragraph 4.5.5.1.3. The procedure and particle count limits are as specified in Table III.

4.5.5.1.8 On standard coordinate graph paper plot percent meter reading versus contamination levels in mg/l. The resulting plot shall be linear over the range 1.0 to 3.0 mg/l, and this range shall extend over a minimum of 40 percent of the contamination monitor meter scale. The dividing line between red and green bars of the contamination monitor meter shall commence at what corresponds to 1.7 mg/l (± 0.2)

Table II

Worksheet for preparing volumetric portions of the concentrated contaminant mixture as required by paragraph 4.5.5.1.3.

The total contaminant required to achieve a given contamination level consists of two parts:

a. The part required by the test loop volume, V-liters, and the amount of change of contaminant level.

b. The part which replaces the amount of contaminant drawn as required by paragraph 4.5.5.1.5.

CW = (P(N) - P(N-1)) * V + (P(N-1)/10)

CW - weight of contaminant to be added, mg.

P(N) - present contaminant level, mg/l.

P(N-1) - previous contaminant level, mg/l.

R - Volume of portion of concentrated contaminant mixture.

P Contamination level, mg/l	Calculation	CW Contam. Wt., mg	R Volume, ml
0.5	0.5 * 10	5.0	96
1.0	((1.0-0.5)*10) + .05	5.05	97
1.5	((1.5-1.0)*10) + .10	5.10	98
2.0	((2.0-1.5)*10) + .15	5.15	99
2.5	((2.5-2.0)*10) + .20	5.20	100
3.0	((3.0-2.5)*10) + .25	5.25	100
3.5	((3.5-3.0)*10) + .30	5.30	101
4.0	((4.0-3.5)*10) + .35	5.35	102
4.5	((4.5-4.0)*10) + .40	5.40	103
5.0	((5.0-4.5)*10) + .45	5.45	104
	Total contaminant required, mg	52.25	
	Total volume, concentrated contaminant mixture, ml		1000

Notes: 1. Calculations are based on a test loop volume of 10 liters.

a. Volumes shown in column 4 are the volumes of the concentrated mixture to be added to the test loop to achieve the desired contamination level.

3. Calculation of Volume R $R_n = \frac{CW_n}{\text{Total Contaminants required}} \times 1000$

Table III

Particulate Count Limits

Contamination level, mg/l		Particle size, micrometers Number Greater than/ml			
		5	10	25	50
0.5	Max	284	79	8	1
1.0	Max	569	158	15	2
1.5	Max	853	238	22	3
2.0	Max	1136	317	30	4
2.5	Max	1421	396	37	5
3.0	Max	1705	475	44	6
3.5	Max	1887	554	52	7
4.0	Max	2274	634	59	8
4.5	Max	2557	713	66	9
5.0	Max	2838	792	73	10

Procedure -

1. Record particle counts per ml greater than 5, 10, 25 and 50 micrometers for each gravimetric level from 0 to 5 mg/l.

2. Subtract the 0 mg/l count from all other particle counts.

3. The resulting particle counts should be within the limits listed in the above table.

4.5.5.2 Contamination clean-up test - Since the contamination monitor will be used most frequently in monitoring the clean-up of an aircraft hydraulic system, it should be tested in this operating mode. This test shall consist of two parts, a laboratory test and a field test. These tests should follow the meter sensitivity test of paragraph 4.5.5.1.

4.5.5.2.1 Contamination clean-up; laboratory test - With AC fine test dust as contaminant, and starting at a contamination level of 5.0 mg/l or higher in the test loop, the test fluid shall be filtered through a depth filter with an absolute rating of 3 micrometers or less until the contamination monitor indicates a satisfactory contamination level within 5 percent scale reading of the satisfactory/unsatisfactory scale boundary. At this point a 100 ml sample of test fluid shall be drawn from the test loop, and a particle count shall be made using one of the methods specified in paragraph 4.5.5.1.7. The particle count should be within acceptable limits as specified in the Aviation Hydraulics Manual, NAVAIR-01-1A-17.

4.5.5.2.2. Contamination clean-up; field test - Using an aircraft and hydraulic test cart the contamination monitor shall be connected to the return flow line as it will be used in service. The aircraft hydraulic system should be contaminated beyond the limits of class 5 cleanliness under conditions representative of normal service. Draw a 100 ml sample of fluid from the aircraft hydraulic system to verify the condition of the system prior to clean-up. A particle count shall be made as specified in paragraph 4.5.5.1.7. Circulate the aircraft hydraulic fluid through the ground test cart until the contamination monitor indicates that satisfactory cleanliness has been achieved. At a point in time where the contamination monitor meter reading is within 5 percent scale reading of the satisfactory/unsatisfactory scale boundary, draw a 100 ml sample of hydraulic fluid from a sample port in the vicinity of the point where the contamination monitor is connected to the test cart return line. A particle count shall be made on this test sample as specified in paragraph 4.5.5.1.7. The particle count shall be within the acceptable limits specified in the Aviation Hydraulics Manual, NAVAIR 01-1A-17.

4.5.6 Operating tests

4.5.6.1 Pressure test - Using a laboratory test loop similar to that described in paragraph 4.5.5.1, and with the monitor operating, the pressure in that portion of the test loop containing the sampling unit described in paragraph 3.2.2.3 shall be varied from 10 to 170 psia in 10 psi increments every 5 minutes without causing physical damage, leakage, or change in meter reading exceeding $\pm$ 5 percent of the reading recorded for the 50 psia pressure setting. Subsequent to this test, the sampling unit shall be subjected to a pressure surge of 350 psi for a period of time not in excess of 1 second. The contamination monitor meter reading after the pressure surge test shall agree within $\pm$ 2 percent of the meter reading recorded at the 50 psia pressure setting.

4.5.6.2 Endurance test - Using a laboratory test loop similar to that described in paragraph 4.5.5.1, the complete contamination monitor shall be subjected to a 50 hour endurance test under the following operating conditions. The test shall consist of ten 5 hour cycles. Each cycle shall start from ambient conditions as specified in paragraph 4.2. The fluid temperature shall be raised to 65° within one hour from the start of the cycle, maintained at that temperature for one hour, and then allowed to drop to 50°C for the remainder of the cycle. At the end of the cycle, power to the contamination monitor shall be turned off while the unit is allowed to cool to ambient conditions for the start of the next cycle. After completing ten cycles, the contamination monitor shall satisfactorily complete the contamination clean-up test of paragraph 4.5.5.2.1.

4.5.6.3 Saturation limit test - With AC fine test dust as a contaminant start at a contamination level no greater than 5.0 mg/l in the test loop and increase the concentration level in steps until the saturation limit is reached as indicated by the activation of the saturation warning light. Record the saturation level and determine that the level is below, or at, the saturation predicted for the device. The test is failed if the monitor fails to show increases in contamination reading prior to the activation of the lights or the light does not function. The test shall be performed two times and the results be within 10% of each other.

4.5.7 Environmental - Environmental testing shall be done after the contamination measurement testing of paragraph 4.5.5. When required during environmental test, the contamination monitor shall be connected to a hydraulic test loop as specified in paragraph 4.5.5.1. The contamination level of the test loop shall be within ± five percent scale reading of the satisfactory/unsatisfactory scale boundary. Deviation of ± 10 percent of scale deflection during test shall be considered a failure unless exception is granted by the procuring activity. All environmental testing shall be by the specified test methods of MIL-STD-810C.

4.5.7.1 Low temperature test - All components of the contamination monitor shall be subjected to the test conditions specified in paragraph 3.3.1.1. After the monitor has stabilized at the low operating temperature, sampling from the test loop shall be begun. The temperature of the fluid in the hydraulic loop shall not exceed 50°C. After sampling has begun and the temperature of the sensing unit has stabilized, the scale reading of the contamination monitor shall be recorded. The monitor shall be operated a minimum of 10 minutes at this condition. It shall be within ± 10 percent of the scale deflection recorded at the start of test for ambient conditions and the same test loop contamination level.

4.5.7.2 High temperature - All components of the contamination monitor shall be subjected to the test conditions specified in paragraph 3.3.1.2. The temperature of the fluid in the test loop shall be stabilized at the same temperature as the operating temperature during test. Sampling of the test loop shall be initiated and the scale reading of the contamination monitor shall be recorded. The

monitor shall be operated a minimum of 10 minutes at this condition. It shall be within ± 10 percent of the scale deflection recorded at the start of test for ambient conditions and the same test loop contamination level. At the conclusion of temperature test the contamination monitor shall be subjected to and meet the accuracy requirements of paragraph 4.5.5.2.1.

4.5.7.3 Shock - The contamination monitor shall be subjected to the shock tests specified in paragraph 3.3.1.3. Operation of the equipment is not required during shock test. At the conclusion of the shock test the contamination monitor shall be tested as specified in paragraph 4.5.5.2.1. The contamination monitor shall be considered to have passed the shock test if there is no evidence of deformation of any part of the unit, and it meets the accuracy requirements of paragraph 4.5.5.2.1.

4.5.7.4 Vibration - The contamination monitor shall be subjected to the vibration test specified in paragraph 3.3.1.4. Operation of the equipment is not required during vibration test. At the conclusion of vibration test the contamination monitor shall be tested as specified in paragraph 4.5.5.2.1. The contamination monitor shall be considered to have passed the vibration test if there is no evidence of mechanical or electrical failure, and it meets the accuracy requirements of paragraph 4.5.5.2.1. The contamination monitor which is selected for vibration test shall be the same one which has successfully completed the shock test.

4.5.7.5 Humidity - The contamination monitor shall be subjected to the test specified in paragraph 3.3.1.5. The contamination monitor shall be operated during test as specified in paragraph 4.5.7.

4.5.7.6 Dust - The contamination monitor shall be subjected to the test specified in paragraph 3.3.1.6. The contamination monitor shall be operated during test step 5 for a period of 10 minutes as specified in paragraph 4.5.7.

4.5.7.7 Rain - The contamination monitor shall be subjected to the test specified in paragraph 3.3.1.7. The contamination monitor shall be operated during test as specified in paragraph 4.5.7 for a minimum of 10 minutes. The same contamination monitor shall be subjected to the humidity, dust, and rain tests. At the conclusion of these tests, the contamination monitor shall be subjected to the meter sensitivity test of paragraph 4.5.5.1. A shift of scale reading for the various contamination levels, in excess of ± 10 percent shall be considered failure of the environmental tests.

4.5.8 Electromagnetic interference, emission, and susceptibility - An electromagnetic interference, emission, and susceptibility test shall be conducted in accordance with MIL-STD-462 to determine conformance with paragraph 3.2.8. Tests shall be conducted on the contamination monitor and all cables connected to it. The contamination monitor shall be operated as described in paragraph 4.5.7 during this test.

4.5.9 Inclined operation - The contamination monitor shall be tested for inclined operation at 30 degrees from the horizontal to determine compliance with paragraph 3.3.2. The unit shall be run at test conditions specified in paragraph 4.2 for a period of not less than one hour at each of the following positions:

a. 30 degrees forward
b. 30 degrees backward
c. 30 degrees to the left side
d. 30 degrees to the right side

Meter readings shall be taken during each of these test conditions. At the conclusion of each phase of the test the contamination monitor shall be returned to level conditions and after the meter reading reaches a stable condition, it shall be recorded and compared with the meter reading during inclined operation. Meter readings shall not differ by more than ± 10 percent of the scale reading.

4.5.10 Reliability demonstration - The contamination monitor provided under this purchase description shall be made to demonstrate its conformance to the reliability requirements set forth in paragraph 3.4. The demonstration test shall follow the contractor's approved test plan in accordance with Test Plan VIII, Test Level A, of MIL-STD-781B. The cycling on-time will be 12 hours vice 3 hours. The ability of the contractor to furnish a contamination monitor that passes this reliability demonstration shall be demonstrated during the Reliability Test.

4.5.10.1 Test procedure - The contractor shall prepare a detailed test procedure to accomplish the Reliability Demonstration Test program for approval by the procuring activity in accordance with 5.1.3 of MIL-STD-781B. The procedure shall include: the facilities required to perform the tests; articles to be tested; a test schedule with expected decision points denoted; measurement endpoints; in addition to the requirements of 5.1.3 of MIL-STD-781B. These tests will be performed at the contractor's facilities. Periodic maintenance shall be performed only during the time before or after a test cycle.

4.5.10.2 Failure categories - Failure classification shall be in accordance with paragraph 4.4 of this specification and paragraph 5.5.1 of MIL-STD-781.

4.5.10.3 Reliability test reports - Reliability Test Reports shall be in accordance with 5.11.1 and 5.11.2 of MIL-STD-781B.

4.5.10.4 Failure during testing - In addition to the failure data required as per MIL-STD-781, the contractor shall provide by written notice a data element representing the total time elapsed to isolate and repair test equipment for each failure occurrence. This shall be provided as part of the monthly summary.
The contractor shall provide parts for all repairs and maintenance and will repair the equipment. Reliability testing shall be resumed following repair implementation. When a test equipment

fails to meet any specified requirement, equipments on hand or later produced shall not be accepted until cause of failure is determined and corrected. The contractor shall explain fully to the Government representative the cause of failure and the action taken to preclude recurrence.

4.5.11 Maintainability demonstration - The contamination monitor shall be made to demonstrate its conformance to the maintainability requirements set forth in paragraph 3.5. The demonstration test shall follow the contractor's proposed test plan in accordance with Method (1), Plan B of MIL-STD-471A. A MTTR of 1 hour and a maximum corrective maintenance down time (Max mean) of 2 hours, shall be used with Method (1). The producer and consumer risk shall be equal to 10%

Maintenance actions resulting from the reliability demonstration tests can be applied as elements of the maintainability demonstration.

The techniques for meeting the MTTR shall be limited to repair as defined in 3.5 of this document.

4.5.11.1 Verification and demonstration test - The contractor shall conduct a coordinated maintainability testing program in accordance with Phase II requirements as defined in 4.1 of MIL-STD-471A.

4.5.11.2 Test procedures - The contractor shall prepare a Maintainability Test Procedures Report in accordance with 4.3 of MIL-STD-471 prior to starting the test.

4.5.11.3 Maintenance Task Selection - The contractor shall prepare a list of realistic and representative maintenance tasks to be used in the Maintainability Demonstration Test in accordance with MIL-STD- 471, Appendix A, and included in Maintainability Demonstration Test Plan.

4.5.11.4 Maintainability test report - The contractor shall provide a final demonstration report in accordance with 4.8 of MIL-STD-471.

4.5.12 Disposition of tested equipment - Tested equipment shall be put into operable condition by the contractor prior to delivery. It shall be calibrated, functionally tested, and submitted for government inspection.

5. Preparation for Delivery

5.1 General - All major units and parts of the equipment shall be preserved, packaged, packed, and marked for the level of shipment specified in the contract or order in accordance with MIL-E-17555 and MIL-STD-794. In the event the equipment is not covered in MIL-E-17555, the method of preservation for level A shall be determined in accordance with the selection chart in Appendix D. of MIL-STD-794.

6. NOTES

6.1 Intended use - The hydraulic fluid contamination monitor is a piece of aircraft ground support equipment which will sample hydraulic fluid flowing from an aircraft to a portable hydraulic ground cart. The sample fluid will be drawn from the return line by the monitor and passed through a sensor or particle counter and then circulated back to the return line and on to the ground cart.

The monitor will determine the particulate contamination level in the sample and provide a read out to the operator on a continuous basis. This read out will be calibrated in such a way that the class of particulate contamination can be determined as a go/no go reading.

6.2 Ordering data - When ordering, the following should be specified in the contract or order, when applicable.

(a) Title, number, and date of this specification.

(b) Specify the number of program reviews (3.4.1.2, 3.5.1.1.2, 3.5.3)

(c) Contract Data Requirements

1. Reliability Program Plan (3.4.1.1)
2. Failure Modes and Effects Analyses (3.4.2.1)
3. Test Plan (4.1.2)
4. Test Report (4.3.1.1)
5. Reliability Test Procedure (4.5.10.1)
6. Reliability Test Report (4.5.10.3)
7. Maintainability Test Procedure (4.5.11.2)
8. Maintainability Test Report (4.5.11.4)
9. Reliability Predictions (3.4.2)

(d) Level of packing required.

(e) Additional data requirements (6.2.1)

6.2.1 Other information - The following additional information should be considered in the preparation of the contract.

(a) Technical Manual Contract Requirements (TMCR)

1. Technical Manuals.
2. Maintenance Requirements Cards.
3. Ground Support Equipment Illustrations.

(b) Provisioning Technical Documentation

(c) Item Identification

1. Federal Stock Number (FSN)
2. Military Type Designator
3. Type Equipment Code

(d) Engineering Drawing Package per MIL-D-1000

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NAEC-GSED-105

1. Hydraulic fluid contamination.
2. In-line contamination monitor.
3. Aluminum oxide hygrometer

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